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A PRELIMINARY TORNADO FORECASTING SYSTEM FOR KANSAS AND NEBRASKA

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ABSTRACT

A study is made of the possibility of associating certain characteristics of the weather situation at 1500 GMT with the occurrence of tornadoes within a specified area during the succeeding 12 hours. The parameters selected were all determined objectively. The system devised was able to separate out a group which included about 30 percent of all reported tornadoes and for which tornadoes were reported in about 60 percent of the cases. The main significance of the study is that apparently the tornado forecasting problem can be successfully treated with the objective forecasting techniques developed in the last decade.

INTRODUCTION

It has generally been realized that tornadoes should be forecast, because of their violent and destructive nature. On the other hand, they occur infrequently in time and widely scattered in space. In order that tornado forecasting may contribute to the saving of life and property, the forecasts should be reliable, otherwise the public would soon become insensitive to warnings.

A quantitative analysis of factors affecting tornado occurrence should contribute greatly to the reliability of forecasts issued. Quantitative analyses have the further advantage that they may be passed to novice forecasters in a form easily grasped and understood. There have been some recent important contributions to tornado forecasting, such as those by Lloyd [1], Showalter and Fulks [2], and Fawbush, Miller, and Starrett [3]. These studies, however, place their main emphasis on conditions contemporary to tornado occurrence. These conditions must be forecast, often in rapidly changing situations. The principles evolved in these studies, and other principles known for many years, do not generally permit of their quantitative application.

It must be recognized that not all tornadoes can be forecast with a high degree of reliability. Since one of the principal requirements of tornado forecasting is reliability, the forecaster is faced with the necessity of issuing forecasts only on days when it is relatively certain that tornadoes will or will not occur. Thus, by some criteria, objective or otherwise, he must be able to separate in advance all days into three groups:

A. Days on which it is certain tornadoes will not occur.

B. Days on which it is certain they will occur.

C. Days on which tornado occurrence is uncertain.

In order to facilitate the discussion, days falling under group A will be called "non-threat days." Similarly, days falling under group B and group C will be called "threat days" and "uncertain days," respectively. The relative value of the forecasts may be judged by the sizes of the three groups relative to each other, and by the degree of certainty in the first two.

Before beginning on a program of making tornado forecasts for the general public, the forecaster should have a good estimate of how reliable his forecasts will be. This requires either a carefully controlled program of practice forecasting and verification over a long period of time, or a quantitative study of factors affecting tornado occurrence in the past. It would be preferable to accomplish both of these tasks, if the pressure of the times permits.

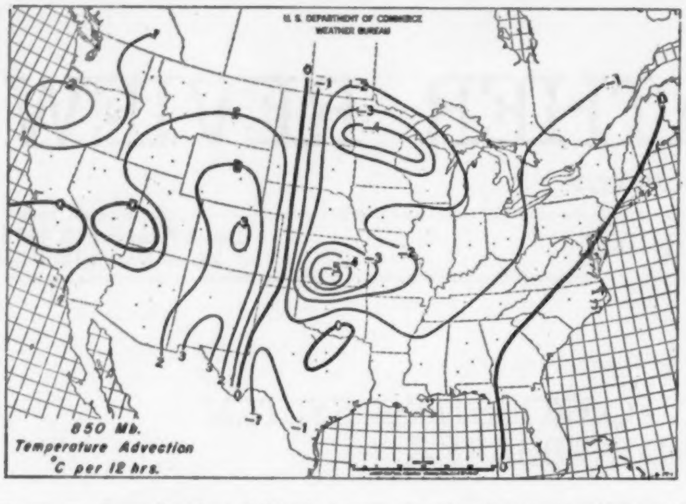

FIGURE 1.—Composite chart of 850-mb. temperature advection on 13 major tornado days during the 24 months of March through June, 1945 through 1950. Only days on which tornadoes occurred in the forecast area (roughly, Kansas and Nebraska—see fig. 4) are included in this composite chart.

The aim was adopted, early in this study, of finding out what is possible in the way of separating tornado days from non-tornado days by quantitative analysis of factors associated with tornado occurrence at lag. The result reported here is an objective system of forecasting tornadoes within a limited area and period. It should prove to be a valuable guide to the forecaster.

The synoptic picture resulting from this study is that tornadoes will occur within 12 hours in Kansas and Nebraska when

1. Maritime tropical air is over or southeast of the area,
2. A deep cold air mass lies west of the area,
3. A well defined pressure trough at 700 mb. lies above the area, and
4. The temperature trough and pressure trough at 700 mb. are out of phase so that there is a strong contrast in temperature advection across the trough.

These physical conditions are often fulfilled when there is a Low over or slightly to the west or north of the area. The relation of tornado occurrence to these conditions will not surprise a forecaster familiar with the meteorology of the two States. The contribution made by this study is the quantitative measure of these conditions represented in figures 2 and 3 which are explained below.

QUANTITATIVE ANALYSIS OF FACTORS ASSOCIATED WITH TORNADO OCCURRENCE

At the outset it should be pointed out that this forecast system represented by the analysis has not been tested on independent data. Independent data which might be used for testing this system would be compromised as test data for another system or for an improvement on this system. Due to scarcity of data, testing will be confined to current data until a forecast system has been developed which is considered as final an answer as possible.

The source of data on tornado occurrence was files of the Climatological Division of the U. S. Weather Bureau. The data analyzed were from the 14 months of May and June 1946–50 and April 1947–50. The forecast system, therefore, should be used only during the months of April, May, and June, although the principles upon which it is based may apply to all seasons. The forecast period is from 0900 CST to 2100 CST. The forecast area is bounded by the meridians 95° and 102° W. and by the latitude circles 38° and 42° N. This area comprises roughly two-thirds of the combined territory of Kansas and Nebraska (see fig. 4).

For the purposes of this discussion the phrase, "non-tornado days", will be taken to mean days on which tornadoes were not reported in the forecast area or period. "Tornado days" will mean days when at least one tornado was reported in the forecast area *and period*. A tornado day will be called "major" if at least 3 tornadoes occurred on that day, at least 2 of which were 100 or more miles apart. Other tornado days will be called "minor".

Many variables were tried as indicators of the synoptic conditions listed in the Introduction. The final selection was made entirely on the basis of their ability to separate all days into the three categories listed on page 233. Four variables were chosen. They are:

- X_1, the 0900 CST (1500 GMT) surface dew point (° C.) at either Columbia, Mo. or Dodge City, Kans., whichever is higher
- X_2, the 0900 CST (1500 GMT) difference (° C.) between the 500-mb. *temperature* at Grand Junction and the surface *temperature* at either Columbia or Dodge City, whichever has the higher *dew point*
- X_3, the 0900 CST (1500 GMT) 700-mb. temperature advection (° C. per 12 hrs.) over the triangle with vertexes at Dodge City, Oklahoma City, and Omaha
- X_4, the 0900 CST (1500 GMT) 700-mb. temperature advection (° C. per 12 hrs.) over the triangle with vertexes at Albuquerque, Big Spring, and North Platte.

X_3 and X_4 were computed by triangulation under the assumption that the wind is geostrophic and the 700-mb. height (z) and temperature (T) fields are linear within each triangle. The formulas used for computations are:

$$X_3 = .008841 \times \left\{ \begin{array}{l} z_{OMA}(T_{DDC}-T_{OKC}) \\ +z_{DDC}(T_{OKC}-T_{OMA}) \\ +z_{OKC}(T_{OMA}-T_{DDC}) \end{array} \right\}$$

$$X_4 = .003147 \times \left\{ \begin{array}{l} z_{ABQ}(T_{BGS}-T_{LBF}) \\ +z_{BGS}(T_{LBF}-T_{ABQ}) \\ +z_{LBF}(T_{ABQ}-T_{BGS}) \end{array} \right\}$$

The derivation of these formulas is carried out in an appendix to this paper. In these formulas, X_3 and X_4 are expressed in Celsius (centigrade) degrees per 12 hours, z in feet, and T in degrees Celsius (centigrade). Positive values of X_3 and X_4 indicate cold air advection, negative values warm air advection.

Figure 1 shows a clue which led to the use of temperature advection as variables. It is a chart of 850-mb. geostrophic temperature advection computed from mean height and temperature charts of major tornado days during March, April, May, and June, 1945–50, a total of 6 years. There were 13 such days during the 6 years. The 13 major tornado days represent only days in which tornadoes occurred in our forecast area, that is, roughly, Kansas and Nebraska.

Temperature advection data at 850, 700, and 500 mb. were compiled for the two triangles, and various combinations of these data were tried as predictors. Temperature advection data at 700 mb. for both triangles were finally selected because they separated best the tornado days from the non-tornado days. It will be noted that the triangles are designed to cover the maximum and minimum in figure 1. Inspection of the mean 700- and 500-mb. height and temperature charts for the same days which figure 1 represents revealed that the triangles also fit the regions of cold and warm temperature advection at these levels.

In figure 2, X_1 and X_2 were plotted against each other for each day of the 14 months of development data. Note that the upper right hand corner is ruled off. This was done in such a way that the ruled-off area contains practically all of the tornado days. Of 38 tornado days, only 2 are outside the ruled-off area.

Days which lie outside the ruled-off area are non-threat days, since the forecaster may be relatively certain that these days will be non-tornado days. Days which lie within the ruled-off area are threat days plus uncertain days, since figure 2 gives the forecaster only the information that these days are not non-threat days. There are 166 threat days and uncertain days, and 257 non-threat days in figure 2. Originally there were 425 days in the 14 months. Upper air data were lacking for 2 days, both of which were non-tornado days.

In figure 3, X_3 and X_4 were plotted against each other for only figure 2 tornado threat days. In figure 3 also, a line was drawn separating the cases into two groups. The line was so drawn that one group contained a substantial number of days, most of which were tornado days.

Days in this group, which lies in the upper left portion of figure 3, are threat days, since the forecaster may be relatively certain that these days will be tornado days. The days lying in the remainder of figure 3 are the uncertain days of this system, in the sense that they have not been satisfactorily separated. There are 20 threat days and 135 uncertain days in figure 3. One or more of the necessary upper air soundings were missing for 11 of the 166 threat days and uncertain days of figure 2. Of the 11 days, 2 are tornado days, 9 non-tornado days. Of the 34 tornado days plotted in figure 3, 12 are threat days, 22 are uncertain days.

As stated previously, the forecaster must be able to separate in advance all days into three groups.

A. Non-threat days: days on which he is certain tornadoes will not occur. In this forecast system, this group corresponds to the non-threat days of figure 2.
B. Threat days: days on which he is fairly certain tornadoes will occur. This group corresponds to the threat days of figure 3.
C. Uncertain days: days on which he is uncertain whether or not tornadoes will occur. This group corresponds to the uncertain days of figure 3.

The relative value of any system, objective or otherwise, may be judged by the sizes of these three groups relative to each other, and the degree of certainty in the first two. The relative sizes and the degrees of certainty are listed below. It will be noted that data were available for only 412 days of the 425 days in the 14 months of development data. Thirty-six of the 412 days were tornado days, 376 non-tornado days. The climatological probability of a day becoming a tornado day is, therefore, P_{ct}= 36/412=.087, as indicated by the 412 days for which data were available.

	Relative size	*Forecast*	*Degree of certainty*
Group A	257/412=.623	No tornadoes	255/257=.992
Group B	20/412=.049	Tornadoes	12/20=.600
Group C	135/412=.328	----------	----------

One question which will inevitably be asked is, "In order to obtain a high degree of certainty in Group B, must the size of Group B be made so small that it no longer contains a substantial number of the tornadoes which occur?" The answer to this question as it applies to this study may be judged from the fact that, of the 36 tornado days for which data were available, 12 fall into Group B. This means that if the system holds in the future, it will forecast 12/36=1/3 of all the tornado days which occur.

The four variables used in this study were suggested by a set of composite charts of tornado days. The Short Range Forecasting Development Section has prepared for major tornado days composite charts of height, temperature, and humidity at 1000, 850, 700, 500, 300, 200, and 100 mb. not only for days on which tornadoes occurred in the Kansas and Nebraska area, but also for days on which tornadoes occurred in four other areas. The total of five areas covers the path of the annual march of the maximum of tornado frequency. Many other variables were tried, but with little or no forecasting success. Included among variables that were less effective as predictors than those discussed above were:

1. Measures of temperature advection at levels other than at 700 mb.
2. Various measures of stability and convective instability.
3. Measures of time-rate of change of convective

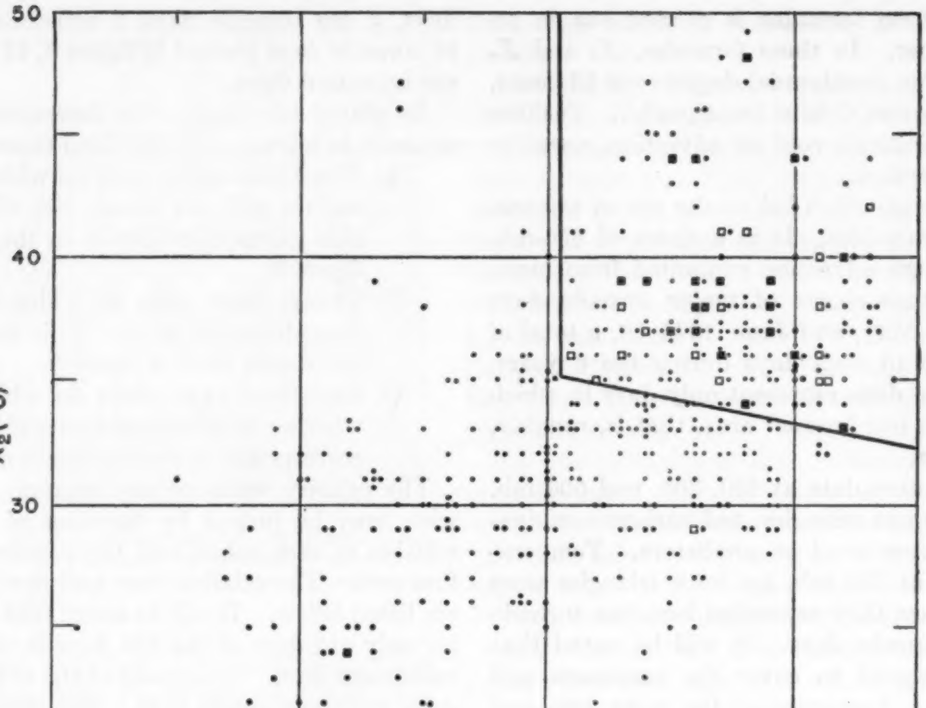

FIGURE 2.—The higher surface dew point (X_1) at Columbia, Mo., or Dodge City, Kans., against the difference (X_2) between the 500-mb. temperature at Grand Junction, Colo., and the surface temperature at either Columbia or Dodge City, whichever has the higher dew point. Temperatures and dew points are expressed in degrees Celsius (centigrade). All quantities were measured at 0900 CST for each day of the 14 months of April, May, and June, 1947 through 1950, and May and June, 1946. The dots are non-tornado days, the squares tornado days. Solid squares are major tornado days, open squares minor tornado days.

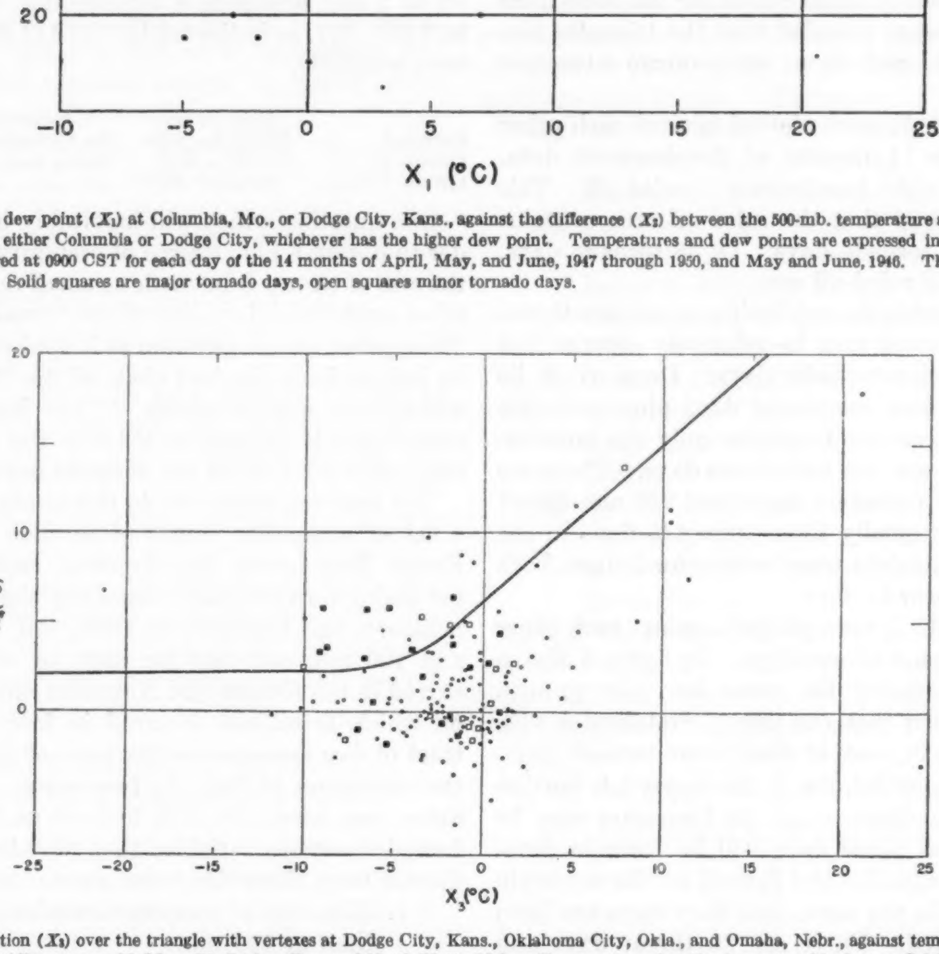

FIGURE 3.—Temperature advection (X_3) over the triangle with vertexes at Dodge City, Kans., Oklahoma City, Okla., and Omaha, Nebr., against temperature advection (X_4) over the triangle with vertexes at Albuquerque, N. Mex., Big Spring, Tex., and North Platte, Nebr. Temperature advection is expressed in degrees Celsius (centigrade) per 12 hours. A positive sign indicates cold air advection. All quantities were measured at 700 mb. at 0900 CST for each of the 166 days which fell in the ruled-off area in the upper right hand corner of figure 2. The dots are non-tornado days, the squares tornado days. Solid squares are major tornado days, open squares minor tornado days.

instability, as determined by advection of equivalent potential temperature at different levels.

4. Measures of wind velocity and direction at 500 mb. (the effect of the Fawbush-Miller-Starrett "jet" was expected to contribute here).
5. Measures of the "funnel" in the equivalent potential temperature isopleths which occur in cross-sections on tornado days. These cross-sections are parts of case studies the Weather Bureau is making of 1951 and 1952 tornado situations.

By removing seasonal trends and introducing a new variable, six non-tornado days were separated out of the 20 threat days in figure 3. Thus, for the remaining 14 days, the degree of certainty was increased to 12/14=.857. In this further step, however, the number of cases being worked with were so few that no great reliance can be placed on the improved separation. The charts showing this refinement are not included here.

In figures 4 through 10, severe local storms which were reported near the area and period are plotted for seven of the eight threat days on which tornadoes did not occur. On the eighth threat day, 26 April 1948, no severe local storms were reported in or near the forecast area and period. The "near miss" character of these non-tornado days should give the forecaster confidence in allowing the system to guide him.

Considering for the moment that the seven threat days of figures 4 through 10 may be called near misses, in that tornadoes or storms closely related to tornadoes occurred

Figure 5.—Severe local storms which occurred on April 23, 1947, for which tornadoes were forecast but did not occur. The forecast area is blocked out, and the forecast period is 0900-2100 CST.

Figure 4.—Severe local storms which occurred on April 4, 1947, for which tornadoes were forecast but did not occur. The forecast area is blocked out, and the forecast period is 0900-2100 CST.

Figure 6.—Severe local storms which occurred on May 12, 1947, for which tornadoes were forecast but did not occur. The forecast area is blocked out, and the forecast period is 0900-2100 CST.

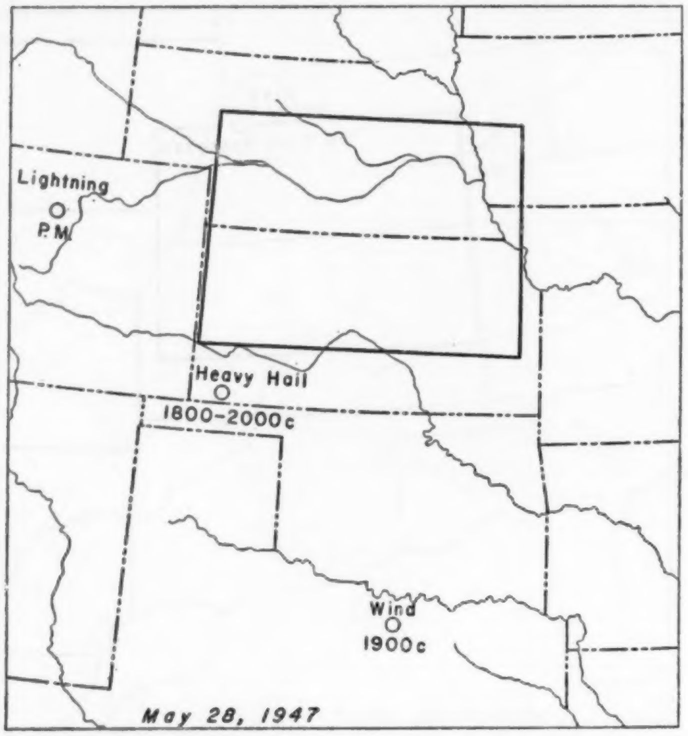

FIGURE 7.—Severe local storms which occurred on May 28, 1947, for which tornadoes were forecast but did not occur. The forecast area is blocked out, and the forecast period is 0900-2100 CST.

FIGURE 9.—Severe local storms which occurred on April 13, 1949, for which tornadoes were forecast but did not occur. The forecast area is blocked out, and the forecast period is 0900-2100 CST.

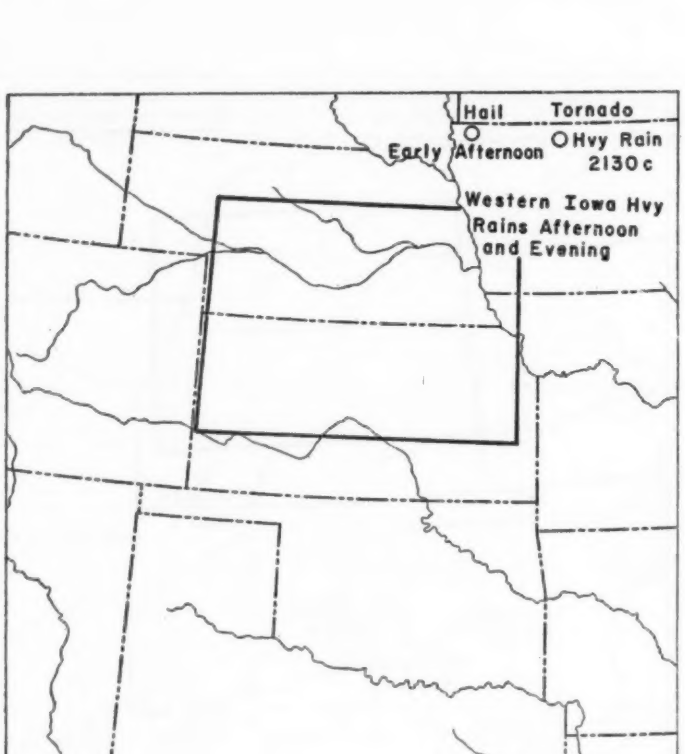

FIGURE 8.—Severe local storms which occurred on June 22, 1947, for which tornadoes were forecast but did not occur. The forecast area is blocked out, and the forecast period is 0900-2100 CST.

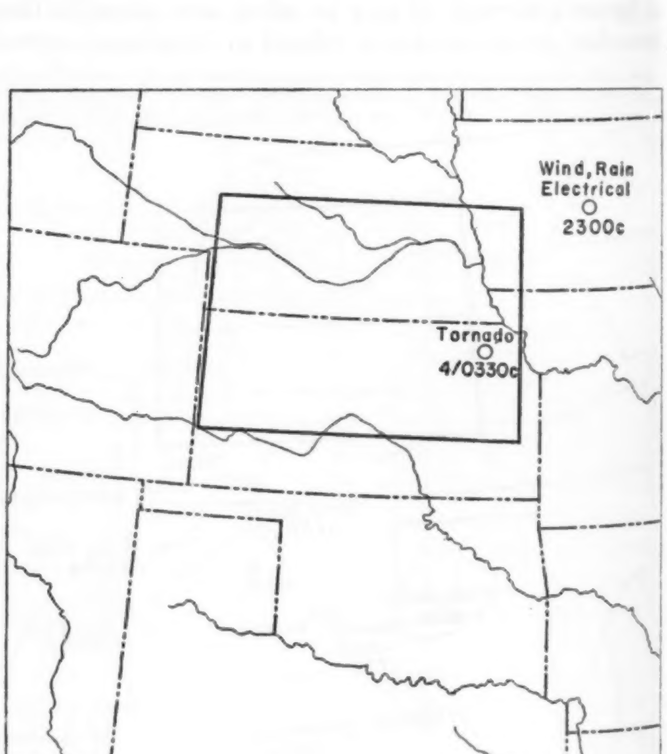

FIGURE 10.—Severe local storms which occurred on May 3, 1950, for which tornadoes were forecast but did not occur. The forecast area is blocked out, and the forecast period is 0900-2100 CST.

in or near the forecast area and during or soon after the forecast period, the probability of a "hit" or "near miss" for days falling under Group B is

$$P_B=0.95.$$

It would be of interest to compare this figure with the corresponding figure for days falling under Group A, the non-threat days. A rough survey of severe local storm data for the 14 months shows that the probability of severe local storms occurring in or near the forecast area and during or soon after the forecast period on non-threat days is

$$P_A<0.37.$$

The precise P_A corresponding to $P_B=0.95$, is probably considerably less than 0.37, since the count of severe local storms was made within an area larger than the area of figures 4 through 10, and no great care was taken in distinguishing *local* severe storms from high winds and heavy rain of a general character, such as those associated with the large-scale cyclones. From the same count, it was determined that the climatological probability of severe storms in or near the forecast area and during or soon after the forecast period is

$$P_{cl}<0.52.$$

CONCLUDING REMARKS

An important conclusion which may be drawn from this study is that objective forecasting techniques may be applied to the tornado problem with some degree of success. In this respect, tornado forecasting is no different from the forecasting of other weather elements. In summarizing this system as a forecasting tool, it must be remembered that it has not been tested on independent data. On dependent data it yielded, with a high degree of accuracy, forecasts of no tornadoes on about 60 percent of all spring days. It indicated in advance a group of days on which forecasts of tornadoes verified fairly well. The latter group of days included about one-third of all tornado days.

As an empirical study this investigation brings out clearly the dependence of tornado occurrence on both humidity and a deep air mass contrast across the area. It also suggests that one set of conditions which favor tornado occurrence, given the former two, is for the two air masses to be in pronounced motion around a 700-mb. trough. This is indicated by the temperature advection chart, figure 1. The failure of stability parameters mentioned previously indicates that stability measurements may not be as good a forecast tool as is now so widely believed. It is not reasonable to suppose that tornadoes occur in the presence of stability. It does not necessarily follow from this fact alone, however, that instability is consistently a useful forecast tool. For instability to be a consistently good forecast tool, it must be capable of being forecast consistently. From experience in forecasting tornadoes during the 1952 season, the authors have found that in some cases instability measurements largely determine a forecast of tornadoes. If these cases are relatively few, an objective technique such as this study would not indicate them clearly. It must also be kept in mind in this connection that the failure of instability parameters may be due to the rigid manner in which they were put into the system. The flexibility of the usual forecasting methods may be better able to make use of instability measurements.

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APPENDIX

DEVELOPMENT OF FORMULAS FOR COMPUTING TEMPERATURE ADVECTION BY TRIANGULATION

List of symbols:

- x,y Cartesian coordinates in a horizontal plane
- u,v x and y components of the velocity, respectively
- z height of a constant pressure surface
- g acceleration of gravity
- f Coriolis parameter
- $\mathbf{V}$ horizontal wind velocity vector
- ∇ horizontal gradient
- A area of the triangle
- T temperature

Consider the triangle of figure 11. Arbitrarily we let one vertex be at the origin, and one side coincide with the x-axis. It is assumed that within the triangle the temperature and height fields are linear, i.e. that they satisfy the following relations,

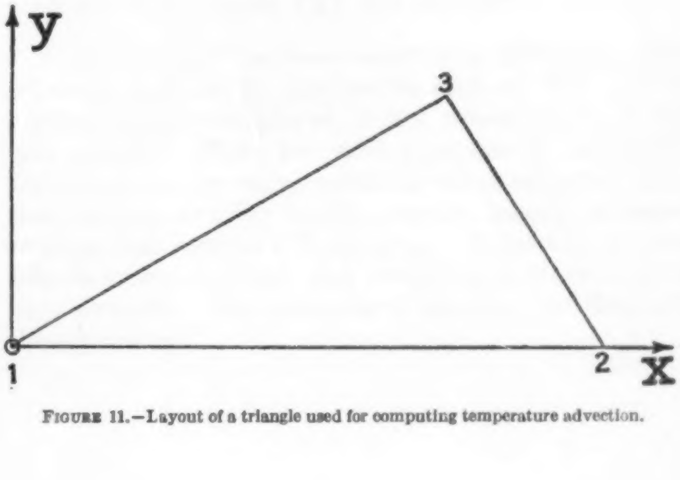

FIGURE 11.—Layout of a triangle used for computing temperature advection.

$$z=a+bx+cy$$
$$T=a'+b'x+c'y \tag{1}$$

where a, b, c, a', b', c' are constants determined by the particular height and temperature fields at hand. It is further assumed that the wind is geostrophic, i.e.,

$$u=-\frac{g}{f}\frac{\partial z}{\partial y}$$
$$v=+\frac{g}{f}\frac{\partial z}{\partial x} \tag{2}$$

The expression for temperature advection is

$$\mathbf{V}\cdot\nabla T=u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y} \tag{3}$$

where a positive value indicates cold air advection.

If substitutions are made from equations (2) into the quantity (3) we find that

$$\mathbf{V}\cdot\nabla T=\frac{g}{f}\left(-\frac{\partial T}{\partial x}\frac{\partial z}{\partial y}+\frac{\partial T}{\partial y}\frac{\partial z}{\partial x}\right) \tag{4}$$

The values for T and z in equations (1) may be substituted into equation (4). Then

$$\mathbf{V}\cdot\nabla T=\frac{g}{f}(-b'c+c'b) \tag{5}$$

The values of b, c, b', c' may be determined by evaluating equations (1) at the 3 vertexes of the triangle of figure 11. The subscripts in the following 2 sets of 3 simultaneous equations refer to values at the vertexes of figure 10.

$$z_1=a$$
$$z_2=a+bx_2$$
$$z_3=a+bx_3+cy_3$$
$$T_1=a'$$
$$T_2=a'+b'x_2$$
$$T_3=a'+b'x_3+c'y_3 \tag{6}$$

If equations (6) are solved simultaneously for b, c, b', c' and the results substituted into equation (5), then

$$\mathbf{V}\cdot\nabla T=\frac{g}{2Af}[(z_2-z_1)(T_3-T_1)-(z_3-z_1)(T_2-T_1)] \tag{7}$$

$$\mathbf{V}\cdot\nabla T=\frac{g}{2Af}[z_1(T_2-T_3)+z_2(T_3-T_1)+z_3(T_1-T_2)] \tag{8}$$

Equation (7) is more adaptable to hand computation, while equation (8) is more adaptable to computation with a hand computing machine.

TORNADO CHARACTERISTICS IN OKLAHOMA

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[Manuscript received September 26, 1952; revised December 15, 1952]

INTRODUCTION

Persons in Oklahoma concerned with tornado warnings and local storm networks have many questions about tornado characteristics. Many of these characteristics, such as distribution by counties, length and width of paths, direction of travel, time of occurrence through the year, and time of occurrence through the day, have been published previously [1], [2].

Charts and tables that follow show analyses of other characteristics of tornadoes in Oklahoma. These analyses are based on data on all tornadoes in the State, for which record is available, from 1951 back through 1875 [3], [4].

WHEN DO TORNADOES OCCUR DURING THE DAY AT DIFFERENT TIMES OF THE YEAR? DO MORE TORNADOES OCCUR DURING THE DAYTIME THAN AFTER DARK?

Two questions commonly asked are when do tornadoes occur during the day at different times of the year, and do more tornadoes occur in the daytime than after dark.

Tornadoes can occur in any hour of the day and in every month of the year in Oklahoma, although maximum frequency is in late afternoon in April and May. Figure 1 shows the hourly distribution by months, as well as for the year, of tornadoes in Oklahoma for which there is record of time of occurrence.

The curved lines in figure 1 show the approximate times of sunrise and sunset, and roughly separate the occurrence of tornadoes between daylight and darkness. This approximate daylight-darkness distribution shows that tornadoes in Oklahoma are about equally divided with 293 daylight occurrences as compared with 248 after dark.

	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	Total
Jan.		1	1	1							2	1					1		2	1			1	1	12
Feb.		1	1						1						1		1		2	3	2	1	1	1	15
Mar.	1		2	2		1		1		1	1			2	1	6	5	5	6	4	8	6	6	6	64
Apr.	2	4		1	1	1	1	1		1		1	5	5	8	15	22	25	15	9	6	7	6	3	139
May	5	9	4	2		1			1	1	2		3	1	11	16	10	25	22	18	19	10	3	3	166
June	3	1		4			1			1	1				4	10	12	10	11	8	7	4	2	3	82
July																1	3	1	1	1					7
Aug											1			1	1	4		1	1						9
Sept.		1	1				1								1		5	1	1			1			12
Oct.	1								1						1	1		1	2	2	5	2	2	2	20
Nov.										3					1	2	2	4	1						13
Dec.										1	1														2
							Sunrise										Sunset								
Total	12	17	9	10	1	3	3	2	2	8	8	2	8	9	29	55	61	73	64	46	47	31	21	19	541

A. M. (CST) P. M.

FIGURE 1.—Hourly occurrence of tornadoes in Oklahoma, 1875–1951. The data are tabulated for the hour *ending* at the indicated time (CST) and are counted for each hour in which tornadoes occurred, i. e., a tornado reported in 2 hours is counted for each hour. The superimposed curves indicate approximate time of sunrise and sunset in central Oklahoma.

Only 95 of the 541 tornadoes, or 18 percent occurred in the 14 hours between midnight and 2 p. m. After 2 p.m. the frequency rises sharply, and in the 5 hours from 2 p.m. to 7 p.m., more than half of all tornadoes occurred. Hourly distribution during the spring, summer, and fall, is much the same as for the entire year. During the winter months, a greater percentage occurred earlier in the day with about 40 percent before 2 p. m. as compared with between 17 percent and 20 percent for other months of the year.

IS THERE ANY DIFFERENCE IN THE HOURLY DISTRIBUTION OF TORNADOES AS RECORDED AT THE PRESENT TIME COMPARED WITH EARLIER YEARS IN OKLAHOMA?

There have been questions regarding the thoroughness with which tornadoes were reported in earlier years of Oklahoma's history, especially those occurring after dark. Figure 2 shows the distribution for different periods in Oklahoma history. If the 1885–1911 and 1912–1921 curves were combined the percentage distribution until about 2 p.m. would be much the same for the different periods. After 2 p.m., the curves show a somewhat greater frequency of tornadoes between 2 p.m. and 7 p.m. in earlier years, suggesting that a number after dark were not reported prior to 1921. After 1921 there seems to be close agreement.

IF ONE TORNADO IS REPORTED IN OKLAHOMA, WHAT IS THE CHANCE OF HAVING TWO OR MORE THAT SAME DAY OR NIGHT?

After a tornado has been reported in Oklahoma, there are many requests for information such as: Will there be another tornado tonight or, Will a tornado strike in this area tonight? These are valid questions by the public. Unfortunately, on many occasions when synoptic conditions are not changing rapidly, positive assurance cannot be given that another will not occur. It has been of some help, however, to advise how tornadoes in previous years have occurred. The remainder of this paper will deal with these questions.

When tornadoes occur in Oklahoma there usually is only a single tornado in any 24-hour period (from noon continuing through the afternoon, evening, and including the few that occur after midnight and before noon the next day). Figure 3 shows the number of occasions on which the indicated number of tornadoes occurred in one day. Two-thirds, or 66 percent were of single occurrence. On about 17 percent of the tornado days there were two tornadoes in the State, and on about 10 percent there were three tornadoes. On only 21 occasions in the entire history of Oklahoma tornadoes, have there been 4 or more tornadoes reported on a given day. The most outstanding of these occasions occurred in 1949, when on May 20–21 there were 21 tornadoes between 5:10 p. m. and 1:10 a. m., and on April 30 when 14 tornadoes were reported between 2:45 p.m. and 7:30 p.m.

WHEN A TORNADO OCCURS IN OKLAHOMA, HOW SOON WILL THE TORNADO ACTIVITY BE OVER?

Table 1 shows the time between beginning and ending of tornado activity in the State. In 76 percent of the times all tornado activity ceased in less than an hour after the first beginning of the tornado. A great many tornadoes were of only a few minutes duration. In only 6 percent of the times has there been tornado activity over a period of more than 6 hours. Some of these tornadoes occurring in a day 6 hours or more apart, were in separate storms.

TABLE 1.—*Time between beginning and ending of tornado activity*

	Less than 1 hour	1 hr.–1:59	2 hr.–2:59	3 hr.–3:59	4 hr.–4:59	5 hr.–5:59	6 hr. or more
Number of times	230	13	17	13	7	2	19

Most tornado activity of less than an hour's duration consisted of a single tornado, while tornado activity of

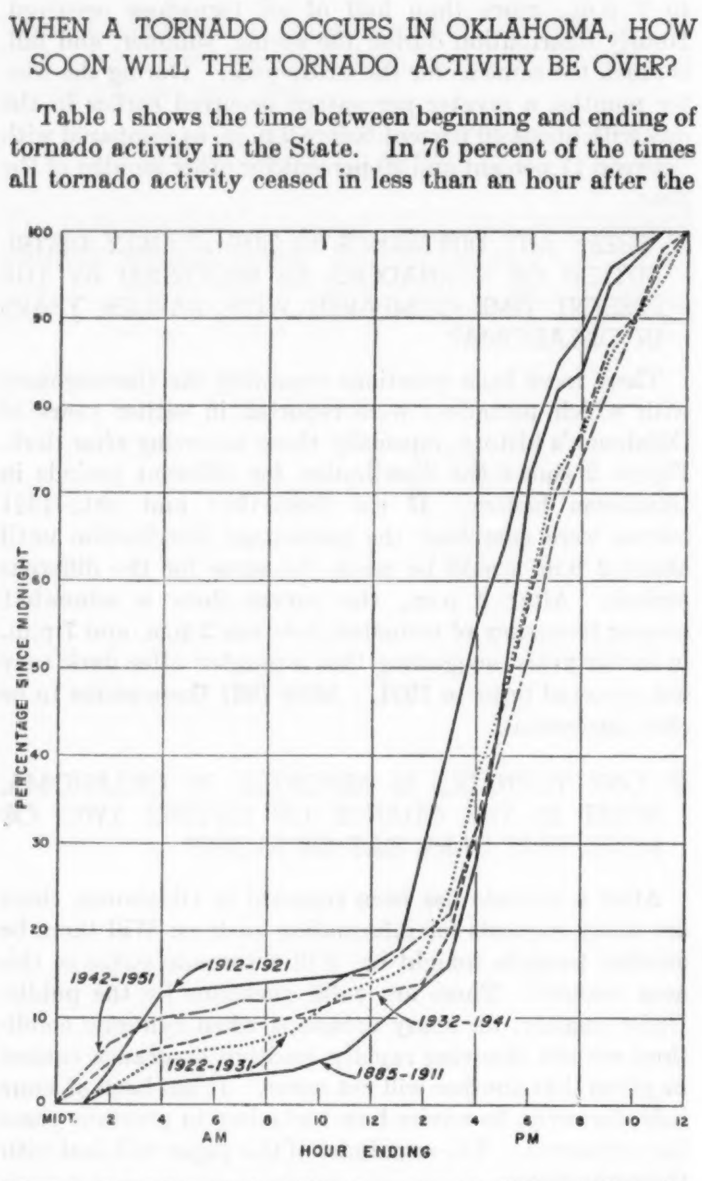

FIGURE 2.—Cumulative percentage of tornado occurrences in Oklahoma by hours since midnight (CST), for the periods 1885–1911, 1912–21, 1922–31, 1932–41, 1942–51.

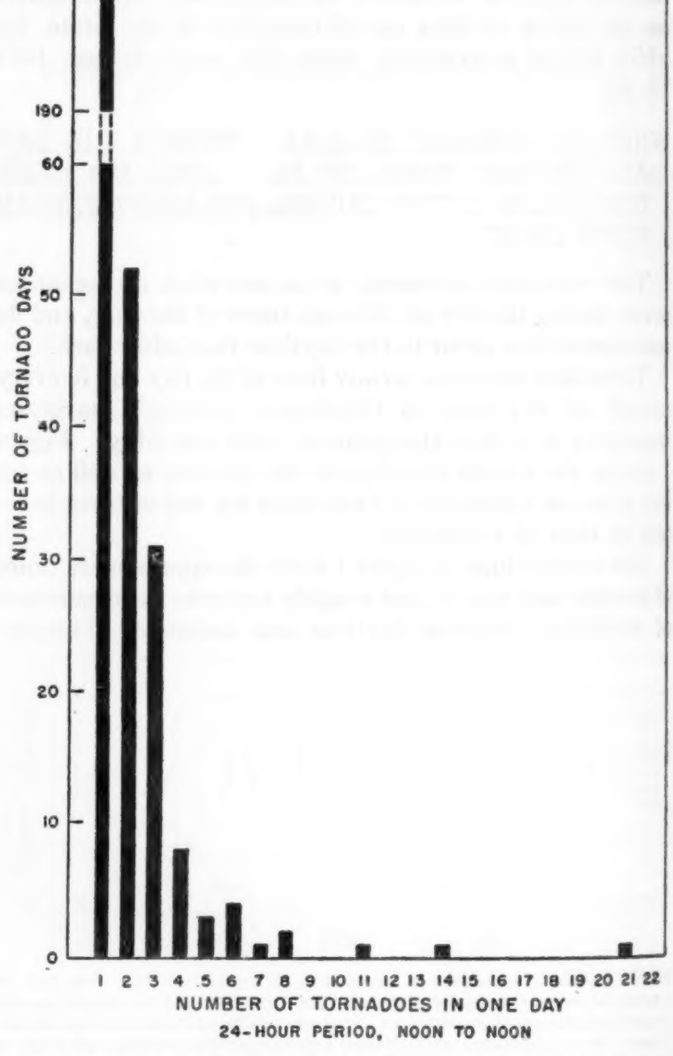

FIGURE 3.—Number of days with the indicated number of tornadoes per day in Oklahoma, 1875–1951.

longer periods, especially of 6 hours or more duration, was made up of a number of tornadoes with natural breaks between.

The duration time for a single tornado in Oklahoma seldom exceeds 3 hours. The longest lasting one was the devastating tornado that caused great destruction and loss of life at Higgins and Glazier, Tex., and Woodward, Okla. on April 9, 1947. In its 221-mile long path from White Deer, Tex. at 5:42 p.m. to near Hartner, Kans. around 11 p.m. there was continuous activity for more than 5 hours. The only other tornadoes in Oklahoma which continued for 3 hours or more were the Canton-Longdale-Blackwell tornado on March 30, 1949, the tornado that struck Wetumka on March 25, 1948, and the one that struck Pawhuska May 2, 1942.

IF A TORNADO STRIKES IN A GIVEN LOCATION, IN WHAT DIRECTION, AND AT WHAT DISTANCE MAY FURTHER ACTIVITY BE EXPECTED?

The 71 occurrences in table 1 where there was tornado activity of 1 hour or more duration, were checked for direction and distance between first and last activity. The results are shown in table 2.

About three-fourths of the tornado activity, when of 1 hour or more duration, continued in the quadrant from NE to SE of the first outbreak. In almost one-third of the cases the last tornado activity was NE of the first occurrence. There was some bias in favor of the directions NE, E, and SE over the adjacent points ENE and ESE, as there was a tendency for observers to report tornadoes moving in a NE, E, or SE direction, rather than in the intermediate directions. Relatively little tornado activity occurred in the westerly directions from the first outbreak.

Distance between first and last activity was usually 50 miles or less. Most of these cases were of less than one hour duration and therefore are not included in table 2. In only 14 cases did tornado activity continue for more than an hour within 50 miles of the first outbreak. The areas for the ≤50, 51–100, 101–150, and ≥151 groupings are not comparable as to size, and the areas involved should be considered in any comparison as to frequency of occurrence between the groups.

TABLE 2.—*Direction and distance between first and last activity (when one hour or more duration)*

Direction between first and last activity	Distance (miles between first and last activity): ≤50	51–100	101–150	≥151	Totals
N					0
NNE		2			2
NE	3	9	5	5	22
ENE		2	1	3	6
E	2	2	1	5	10
ESE	1		1		2
SE	4	3	5	2	14
SSE	1			1	2
S					0
SSW			1		1
SW	2	3			5
WSW			1		1
W	1		1		2
WNW		1			1
NW		1		1	2
NNW			1		1
Totals	14	23	17	17	71

ACKNOWLEDGMENTS

The writer acknowledges, with thanks, encouragement and suggestions for these analyses by Mr. W. E. Maughan, Meteorologist in Charge, U. S. Weather Bureau, Oklahoma City, Mr. H. E. Altman, SR & F Division, U. S. Weather Bureau, Washington, D. C., and the reviewers for the *Monthly Weather Review*.

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USE OF THE TERM "CELSIUS" INSTEAD OF "CENTIGRADE"

and Other Notes on the International Temperature Scale of 1948

The name "Celsius" will be used to designate the centigrade degree of temperature in official communications, publications, manuals, records, forms, etc., published by the U. S. Weather Bureau after January 1, 1953. Adoption of the term "Celsius" in place of "centigrade" should cause little confusion to the layman since most weather reports that reach the public express and will continue to express temperature in Fahrenheit degrees. In those phases of Weather Bureau work where the centigrade scale is used, no difficulty in making the changeover is anticipated, for the degree unit usually will be abbreviated by using the symbol °C. Thus the symbol for degree Celsius is the same as that previously used for degree centigrade. However, to avoid any possible confusion when the term is spelled out, it will appear as "degree Celsius (centigrade)" in all official material printed during a transition period from January 1 to December 31, 1953.

Use of the term "Celsius" conforms with the official decision of the Ninth General Conference on Weights and Measures in 1948 [1] and is desirable in the Weather Bureau for the sake of uniformity in view of the international connections of meteorology. The term has been widely accepted since its recommendation by this international authority on weights and measures and is now found in the publications of many scientific agencies, including the World Meteorological Organization and the International Civil Aviation Organization. In the United States, the National Bureau of Standards has recommended using the term "Celsius" [2].

The Conference made its decision to resolve a question in language that was posed by the trilogy of terms, centigrade, centesimal, and Celsius, by which the same temperature scale was known in different countries. In favor of the selection of the term Celsius, besides its general use in Scandinavia, Germany, and some other countries for many years, was the appropriateness of naming the centigrade scale in honor of a person who had advanced the science of thermometry, just as other scales recognize the contributions of Fahrenheit, Reaumur, Kelvin, and Rankine.[1] Anders Celsius, professor of astronomy at Uppsala, in 1742 proposed [3] a thermometric scale with 100° at the melting point of ice and 0° at the boiling point of water [4]. While the modern centigrade scale, on which these values are reversed, has been credited to Christin of Lyons (c. f. [5]) and to Linnaeus (c. f. [6]) (the latter a contemporary of Celsius at Uppsala), Celsius' specification of the fundamental 100-degree interval between boiling and freezing points of water is now accorded international recognition by the Conference's decision to name the scale "Celsius".

It seems appropriate in this announcement of the Weather Bureau's use of the term "Celsius" also to call readers' attention to the specifications of the International Temperature Scale of 1948 that was approved by the Ninth General Conference on Weights and Measures [1]. The Scale of 1948 is designed to conform as nearly as practicable to the thermodynamic temperature scale (Kelvin scale [7]) while incorporating refinements to make the scale more uniform and reproducible than its predecessor, the International Temperature Scale adopted in 1927.[2] Among the specifications are six primary and fundamental fixed points selected for their reproducibility. The assigned numerical values and the definitions of these fixed points are shown in table 1. The last decimal place given for each value represents the degree of reproducibility of that point. Although the two fundamental fixed points of the Celsius scale remain the ice point (0° C.) and the steam point (100° C.), a resolution adopted by the Conference defines the zero of the thermodynamic Celsius (centigrade) scale as being the temperature 0.0100 degree below that of the triple point of pure water. This definition was adopted because the triple point of water, with present-day techniques, can be determined more precisely than the "melting point of ice." While the International Temperature Scale of 1948 does not have a value of the ice point specified on the Kelvin scale agreed upon by all

[1] See footnote 3 on p. 245.

[2] The differences between the 1948 and 1927 Scales have been discussed by Corruccini [8].

TABLE 1.—*Fundamental and primary fixed points under the standard pressure* of 1,013,250 dynes/cm.*[2] (*After Stimson* [*12*])

Fixed point	Equilibrium temperature	Assigned value ° C.
Oxygen point	Temperature of equilibrium between liquid oxygen and its vapor.	−182.970
Ice point (fundamental fixed point).	Temperature of equilibrium between ice and air saturated water.	0
Steam point (fundamental fixed point).	Temperature of equilibrium between liquid water and its vapor.	100
Sulfur point	Temperature of equilibrium between liquid sulfur and its vapor.	444.600
Silver point	Temperature of equilibrium between solid and liquid silver.	960.8
Gold point	Temperature of equilibrium between solid and liquid gold.	1063.0

*It is of interest to note that the standard pressure (one atmosphere) is now defined in absolute terms, 1,013,250 dynes/cm[2] (=1013.250 mb.), rather than in millimeters of mercury under specified purity, and temperature or density, and gravity as in the 1927 definition.

nations, it may be noted that the Conference considered 273.15°. This was not ratified and the United States representative pointed out that 273.16° K. was widely used in United States literature (see Birge [9]). Subsequently, the International Meteorological Organization adopted 273.16° as the ice point on the Kelvin scale [3] at its meeting of 1947 [10].

Other specifications of the International Temperature Scale of 1948 describe the means for interpolating temperatures on the scale. For a concise account of this and related topics on the present status of the International Temperature Scale readers may refer to an article by Stimson [2]. The technical details concerning the fixed and reproducible equilibrium temperatures and the specified interpolation formulas relating temperature to the indications of specified measuring instruments are given in the official text of the International Temperature Scale of 1948 [11], an English translation of which has been presented by Stimson [12]. An interesting description of the work of the National Bureau of Standards in maintaining the International Temperature Scale and in calibrating standard temperature-measuring instruments has been given recently by Wilson [13].

ACKNOWLEDGMENTS

Suggestions by Dr. H. F. Stimson of the National Bureau of Standards and Mr. L. P. Harrison of the Weather Bureau were helpful in preparing this note.—Editor.

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[3] Readers not familiar with the relationships among degrees on the Kelvin, Rankine, Celsius, Fahrenheit, Reaumur, and approximate absolute scales are referred to p. 17 of *Smithsonian Meteorological Tables,* 6th Revised Edition, Washington, 1951.

THE WEATHER AND CIRCULATION OF DECEMBER 1952[1]

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THE BROAD SCALE CIRCULATION PATTERN

The monthly mean contours at 700 mb. for December 1952 (fig. 1) indicate that the important North American features included: a low latitude trough off the Californias, ridge conditions from Utah northward through Alberta, and a weak trough extending northeastward from Arkansas to western Quebec and then northwestward. Although heights over the United States were not far from normal, adjacent areas, especially the Gulf of Alaska, Canada, and southern Greenland, had more significant departures. A vigorous Gulf of Alaska Low was accompanied by heights

[1] See charts I to XV following page 255 for analyzed climatological data for the month.

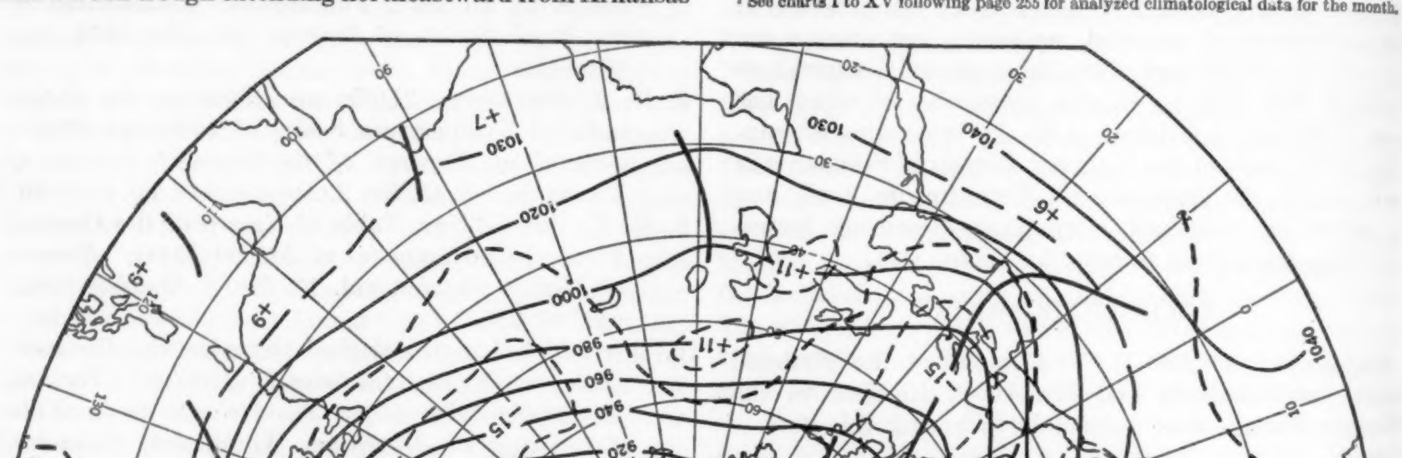

FIGURE 1.—Mean 700-mb. height contours and departures from normal (both labeled in tens of feet) for November 29–December 28, 1952. Note unusual intensity of Gulf of Alaska Low and continued (from November) blocking over North Atlantic.

420 ft. below normal at 700 mb. and pressure 16 mb. below normal at sea level (chart XI inset). Fronts and cyclones emanating from this center of action repeatedly traversed Canada and the northern United States (chart X). The sea level mean map for the month (chart XI) shows the effects of this activity of maritime origin in the presence of a zonal trough across central Canada and in the lack of the more customary extension of polar high pressure southward. As a result sea-level pressures averaged well below normal across all of Canada except the eastern quarter.

Coupled with the Pacific abnormality was a positive departure of 490 ft. at 700 mb. (+15 mb. at sea level) over southern Greenland. The continued presence of above normal heights and pressures across the northern Atlantic since their inception there in early November [1] has been a dominant characteristic of the season. As a consequence the Atlantic westerlies were much weaker than normal again, and blocking activity was once more prevalent. The strong low latitude trough east of Bermuda (fig. 1) is a frequent counterpart to such activity.

Since it is difficult to determine direct cause and effect relationships between circulation features so widely separated as the Gulf of Alaska and Greenland, it is of interest to note that the general pressure distribution of this December is not uncommon. This is shown by figure 2, a composite map made by averaging the ten 5-day mean 700-mb. maps (in 5 winters of data) which had the largest negative height departures centered in the Gulf of Alaska (more exactly, 50° N., 150°–160° W.). This map was prepared by D. Martin in the course of an investigation which seeks to identify the hemispheric interrelationships of strong circulation features [2]. In this case, the general correspondence of wave pattern and height anomaly features between figures 1 and 2 would tend to indicate that the association between negative anomalies in the Gulf of Alaska and positive anomalies in Greenland and the northern Atlantic is not fortuitous. This association is, perhaps, more evident in the temperature field where above normal warmth affected most of Canada and Greenland.

The monthly mean thickness departure from normal (between 1000 and 700 mb.), figure 3, shows the intensity and distribution of these unusually warm conditions. The western sections of this anomaly probably resulted from a strong influx of maritime air from the Gulf of Alaska Low. The vast extension of warm air eastward to Greenland is readily associated with the sea level pressure departures from normal (chart XI inset). Abnormally strong southerly components of flow (relative to normal) are indicated from Greenland through western Canada. These suggest that maritime Atlantic air, in conjunction with the high latitude block, augmented the effects of the strong influx of mild Pacific air.

An additional aspect of the broad scale circulation is shown in figure 4, the average 200-mb. contours and isotachs for the same period as figure 1. The general characteristics of the circulation at 200 mb. were quite similar to those at the 700-mb. level. An intense jet over southern Japan, a familiar winter phenomenon in the area [3], gradually weakened as it crossed the Pacific. The axis of the mean jet reached fairly low latitudes (25° N.) in the eastern Pacific trough and then swung northeastward through the northern Gulf States. A center of maximum wind speed was located near the western Atlantic trough, but it was displaced south of its normal position, a symptom of blocking in the Atlantic. The poorly defined central and eastern Atlantic jet and the secondary minor wind-speed maxima at middle and higher latitudes, were additional tokens of the Atlantic block. Particularly striking is the contrast in wind speed between the 72 m. p. s. jet maximum in the Pacific and the 41 m. p. s. maximum in the Atlantic; this ratio is normally about 4 to 3.

SURFACE WEATHER RELATED TO MEAN CIRCULATION

As might be anticipated from the thickness anomaly,

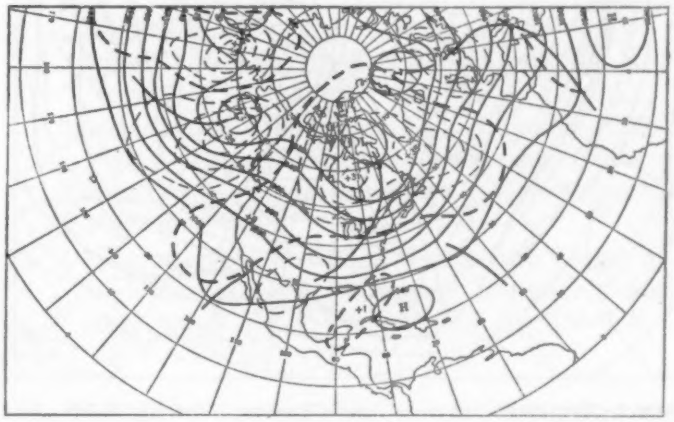

FIGURE 2.—Mean 700-mb. height contours and departures from normal (both labeled in tens of feet) for the ten 5-day mean 700-mb. charts in winter which had maximum negative height departures centered in the Gulf of Alaska. Note similarity of features and phase to figure 1, especially the strong center of above normal heights over Greenland common to both maps.

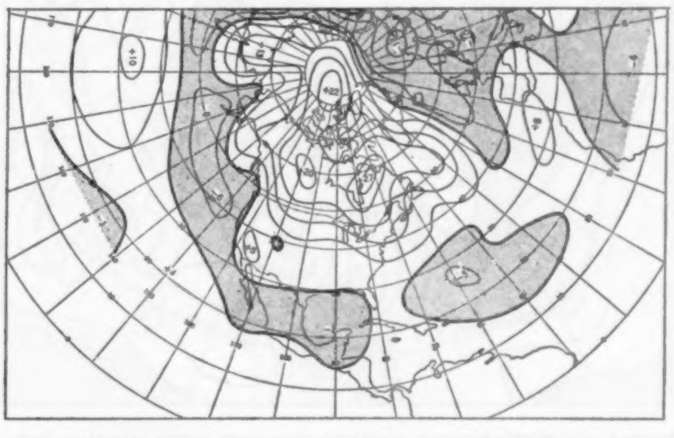

FIGURE 3.—Mean departure from normal of thickness (1000-700 mb.) for November 29–December 28, 1952, analyzed for intervals of 50 ft. with centers labeled in tens of feet. Above normal thicknesses covered most of North America, and centers of +270 and +200 feet occurred in Canada, corresponding to mean virtual temperatures about 9° and 7° C. above normal.

figure 3, surface temperatures over the United States were relatively mild (see chart I-B). The northern States had the greatest positive anomalies with +8° F. in North Dakota and Sault Ste. Marie, Mich. The only two areas significantly below normal (about 2° F.) were part of the Central Plains and the extreme Southeast. This general temperature regime is typical of a winter month during which the normally cold air of the Canadian source region is greatly modified. Thus, air masses entering the United States from Canada were not cold enough to produce below normal average temperature except in the lowest latitudes where normals are the highest. In addition, the general flat westerly circulation (fig. 1), with only a weak western Canadian ridge, was not the type associated with frequent and rapid production of cold Highs over British Columbia or the Yukon, nor was it apt to produce rapid southeastward translation if any cold Highs were to form.

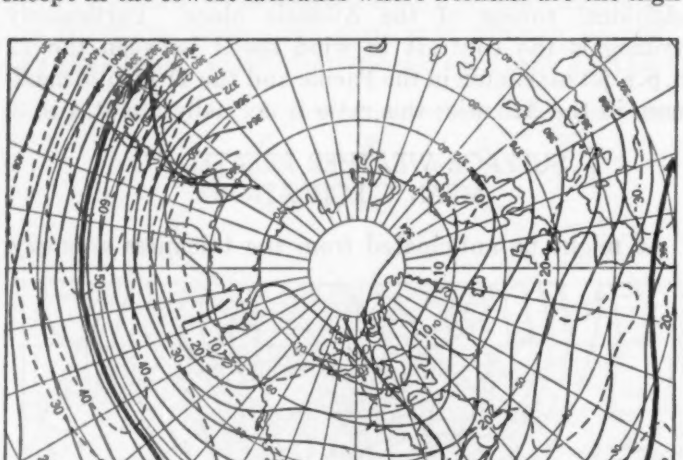

FIGURE 4.—Mean 200-mb. contours and isotachs November 29–December 28, 1952. Solid arrow indicates average "jet" which reached a value of 155 to 160 m. p. h. over southern Japan. Atlantic "jet" is farther south and weaker than normal in conjunction with blocking activity.

Further illustration of this condition is provided by figure 5 which shows the geographical distribution of anticyclonic passages. One maximum, over the eastern Great Basin, was mostly a result of Pacific pressure surges which often accompany prolonged cyclonic activity in the Gulf of Alaska. Another maximum, in the southern Mississippi Valley, was associated with eastward moving high pressure areas which were usually a combination of surges, the major contribution coming from the Great Basin, a minor one from Canada. This sequence occasionally involved the splitting of one high-pressure area into two anticyclones, one in the South Central United States, the other in New England. These anticyclones were generally composed of modified maritime polar air masses and were seldom cold through deep layers.

As illustrated in figure 6, cyclonic activity was quite frequent and intense in the Gulf of Alaska. Very few of these Lows managed to cross the mountains of western North America, but the associated upper-level perturbations and fronts traversed the mountains and produced many of the cyclones in western Canada. The major cyclonic activity affecting the United States occurred in two well-defined tracks: 1. from the Panhandle region northeastward through the central Great Lakes area, and 2. along the East Coast from off Florida to south of Nova Scotia. The former track was associated with the central United States trough, and many of the Lows appeared as secondary disturbances forming on trailing fronts of Canadian cyclones. In somewhat similar fashion quite a

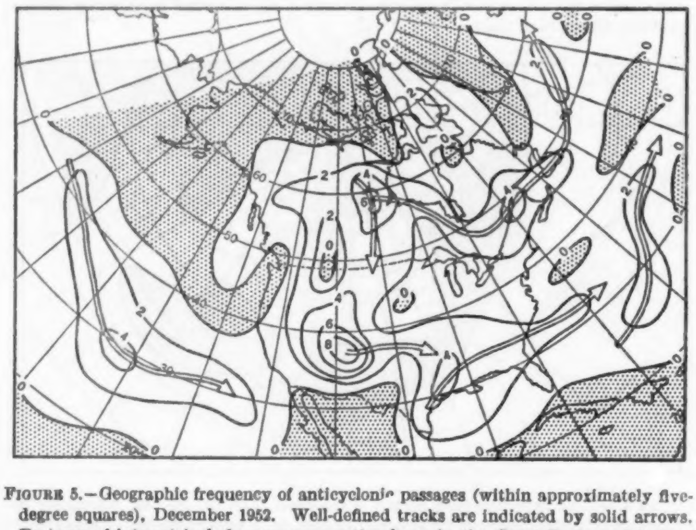

FIGURE 5.—Geographic frequency of anticyclonic passages (within approximately five-degree squares), December 1952. Well-defined tracks are indicated by solid arrows. Features of interest include numerous anticyclones in the Great Basin and lack of anticyclonic activity in the mountains of western Canada. Data derived from chart IX.

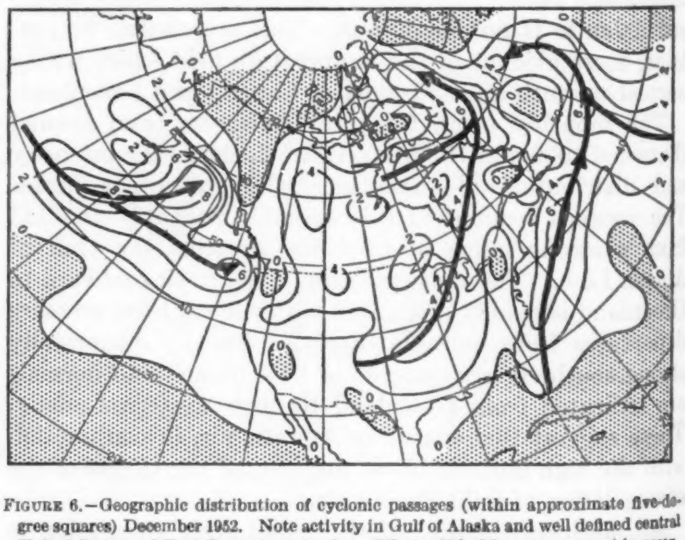

FIGURE 6.—Geographic distribution of cyclonic passages (within approximate five-degree squares) December 1952. Note activity in Gulf of Alaska and well defined central United States and East Coast storm tracks. Effects of blocking are apparent in eccentricities of Atlantic trajectories. All data derived from chart X.

few of the Atlantic coastal storms [2] were secondary developments of primary disturbances in the Lake region. Those cyclonic developments in the central United States accounted for near to above-normal precipitation in the Mississippi Valley and southern and central Great Plains (chart III–B). The coastal storms caused above-normal precipitation over most of New England and the eastern Middle Atlantic States.

Above-normal precipitation was also recorded in the Far West. It was associated with the mean 700-mb. trough at low latitudes and the maximum cyclonic curvature at higher latitudes of the United States. The daily synoptic counterparts related to these features were numerous frontal and 700-mb. troughs which spun from the Gulf of Alaska vortex and released copious amounts of precipitation as they entered the western United States. Below-normal precipitation was recorded in a broad band from Montana through Minnesota south-southwestward to western Texas, New Mexico, and Arizona. The deficiency in northern sections may be associated with foehn drying of prevailing northwesterly winds to the east of the mean ridge. At lower latitudes the persistent sea level anticyclone over the eastern Great Basin, and its eastern extensions, precluded cyclonic activity of significance.

WEATHER HIGHLIGHTS

Despite the relatively mild aspects of the December averages, this month as usual had its vagaries. Toward the end of its first week wind, rain, and snow struck northern California taking 5 lives and stranding 7 passenger trains. Less spectacular but possibly even more impressive was the fog which gripped the Central and South Atlantic Coast on the 6th and 7th, causing numerous transportation delays. London suffered the worst fog in years at almost the same time. It persisted for 4 days and was held responsible for an increase of 2,800 in the total number of London deaths noted the week ending December 13. A shorter-lived but intense recurrence of fog affected London again on the 26th.

The central United States storms created near-blizzard conditions over the Plains at times and several of the coastal storms spread quantities of snow over New England. Inclemency affected even Florida when a high-pressure area moving eastward from the southern Mississippi Valley spread frost as far south as the Everglades, and 26° F. was recorded at Tallahassee on the 12th.

[2] See adjacent article by Brown and Roe for a detailed description of one of these coastal storms.

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THE NEW ENGLAND SLEET STORM, DECEMBER 22-24, 1952

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INTRODUCTION

Winter began with a cyclone bringing stormy weather to much of the Atlantic Coastal Region of the United States, particularly New England. A wave which originated in the Carolinas occluded off Hatteras, N. C. on December 21, 1952. For the next 2 days the occluded system moved east-northeastward and on the third day it recurved abruptly to the north. During these 3 days, New England had rain, freezing rain, sleet, snow, and strong winds which caused inconvenience and damage. Most of the precipitation was sleet which fell for 18 consecutive hours, contrary to the usual rapid transition from sleet to rain or snow.

The duration of the precipitation in New England depended primarily upon the movement of the storm. Forecasting the duration therefore hinged on the difficult problem of forecasting movement. Some aspects of the problem are examined from a synoptic viewpoint. Inspection of the entire storm behavior leads to the conclusion that blocking conditions were developing in the Atlantic.

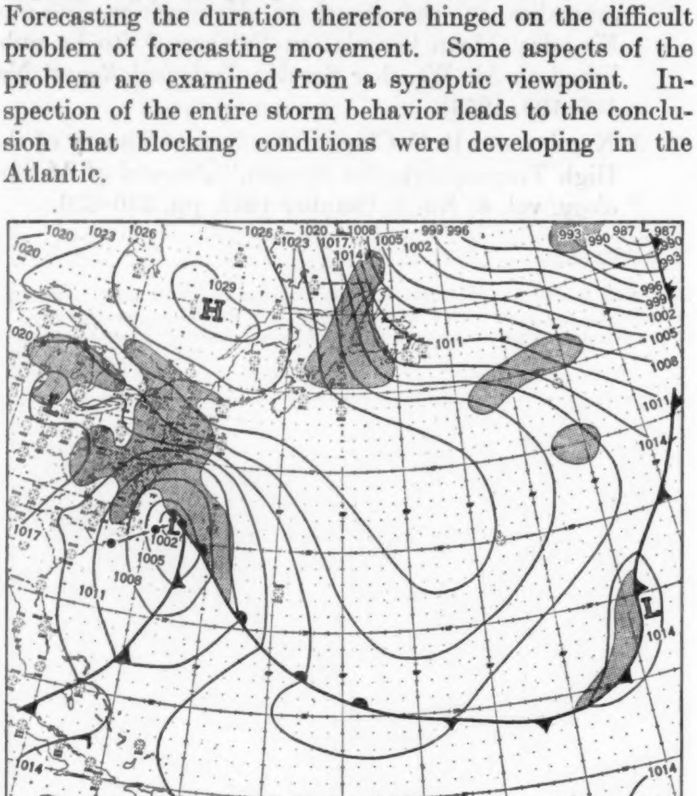

FIGURE 1.—Surface weather chart for 1830 GMT, December 21, 1952, as precipitation (shaded) began in southern New England. Small circles connected by arrows indicate past positions of the intensifying Atlantic coastal Low at 6-hour intervals. From these positions deceleration is apparent.

DEVELOPMENT OF THE STORM

As an occluded system moved over the Great Lakes early on December 21, 1952, a wave formed on the warm front which extended along the East Coast. This pattern, a typical example of Miller's type B East Coast cyclogenesis [1], continued to develop according to the Miller model. The old center over the Lakes filled as the new Low deepened. By 1830 GMT, December 21 (fig. 1), little circulation remained of the original surface Low and the old occluded frontal system was completely gone; the new Low gained a strong circulation, and the frontal wave occluded.

Until 1500 GMT, December 21, the mid-troposphere, e. g. at 500 mb., was changing uniformly. For the most part, the 500-mb. wave pattern was translated simply, with the isotherms remaining in phase with the contours and with both sets of isopleths remaining unchanged. The cold, short, wave trough originally associated with the old surface Low moved rapidly and regularly to the Appalachians where it influenced the development of the secondary surface Low. But by 1500 GMT (fig. 2) the 500-mb. wave pattern became asymmetrical and the trough associated with the new surface Low assumed a northwest-southeast tilt.

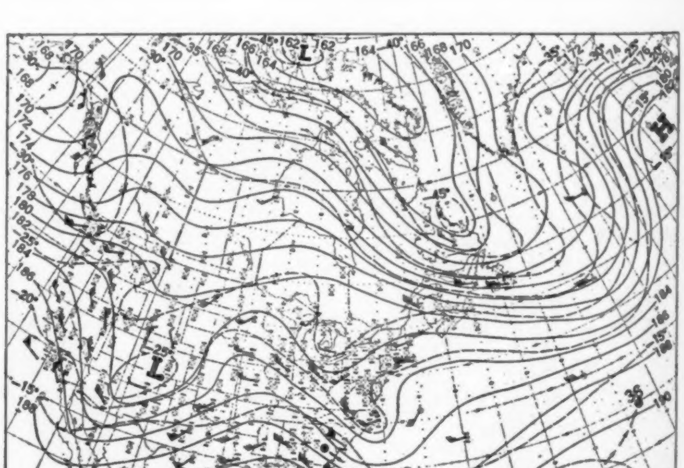

FIGURE 2.—500-mb. chart for 1500 GMT, December 21, 1952. Arrows indicate constant vorticity trajectory. Numbers show position at end of 12, 24, and 36 hours. Contours (solid lines) are labeled in hundreds of geopotential feet. Isotherms (dashed lines) are in °C.

MOVEMENT OF THE STORM

The duration of the precipitation over New England was only slightly prolonged by the small increase in the intensity of the storm. This intensification was indicated only by the increase in the number of isobars around the Low as the central pressure remained the same.

Far more important than the effect of intensity—at least to the extent that intensification and movement are independent—was the failure of the storm to move rapidly away from New England. The direction of movement after 1830 GMT, December 21, was east-northeast, the same as for the previous 12 hours. Not only did the direction agree with extrapolation but it remained the most probable direction as given by Miller's chart [1] of frequencies of movement for East Coast cyclones. This direction would have taken the storm away from New England if the storm had not rapidly decelerated. Deceleration from 30 knots to 12 knots was apparent on the 1830 GMT, December 21, surface chart (fig. 1) although the slowdown was not apparent in the upper air 3½ hours earlier. The speed was not extrapolatable and for the next 48 hours averaged 8 knots, while from the same chart of Miller's as above, 22 knots was the most probable speed. Thus, the problem of forecasting the duration of precipitation resolved itself into forecasting the speed of the storm.

As extrapolation often fails, a comprehensive understanding of the behavior of cyclones is needed, even, as in this case, to forecast a single element, speed. Because there is no such complete theory, the synoptic meteorologist must seek clues to the solution of the problem of speed by investigating such influences as blocking, conservation of vorticity, and thermal field. Some of the clues yielded by investigation of the December storm are discussed in this section.

During November 1952, a significant feature of the general circulation in the Atlantic had been a blocking condition [2, 3]. Namias [4] states that a low index feature (such as blocking) is apt to repeat in the same fashion in the same season. The possibility that the blocking feature had repeated by 1500 GMT, December 21 (fig. 2) so that by this time a block might have existed to the east of the storm, therefore was investigated. Criteria for a block, in a form that can be used in conjunction with synoptic charts, are given by Rex [5]. He considers blocking to be initiated whenever the basic westerly current splits into two branches with one branch turning northward and the other branch turning southward. Over the western Atlantic the flow at 500 mb., 1500 GMT, December 21, did not conform to this pattern, therefore a block was not considered apparent. As Rex's definition came from a study of blocking in the eastern Atlantic there was the possibility that it might not be equally valid in the western Atlantic. A less restrictive definition by Elliott and Smith [6] states that when blocking exists temperatures and pressures in the blocking ridge are considerably above normal. The five-day mean 700-mb. height departure from normal, for the period December 17-21 (fig. 3), as drawn by the Weather Bureau's Extended Forecast Section, shows that the heights to the east of the storm were near or below normal. Thus, the presence of blocking in this situation was not indicated by the criteria of either Rex or Elliott and Smith, and therefore deceleration of the storm due to blocking could not be assumed.

If the speed of the 500-mb. trough associated with the storm could have been forecasted then the speed of the surface Low would have followed assuming that the association remained nearly the same. Petterssen's formula [7] for determining the speed of waves, including short waves, at 500 mb. was not applicable to this case,

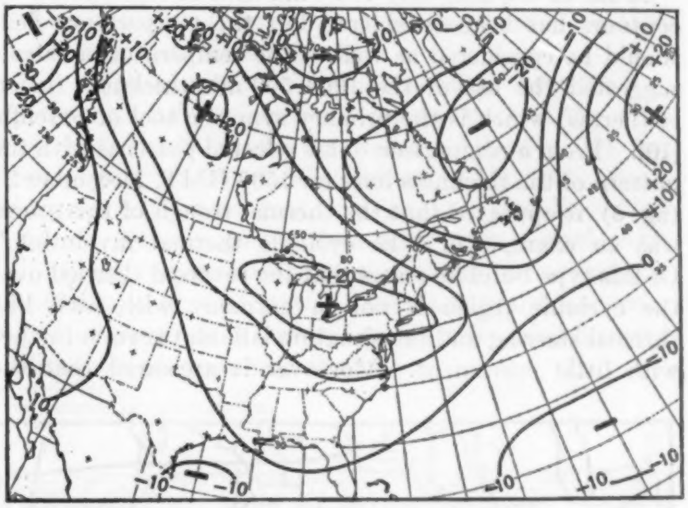

FIGURE 3.—700-mb. height departure from normal for the period December 17-21, 1952. Note near and below normal heights (labeled in tens of feet) to east of storm area. Chart prepared by Extended Forecast Section, U. S. Weather Bureau.

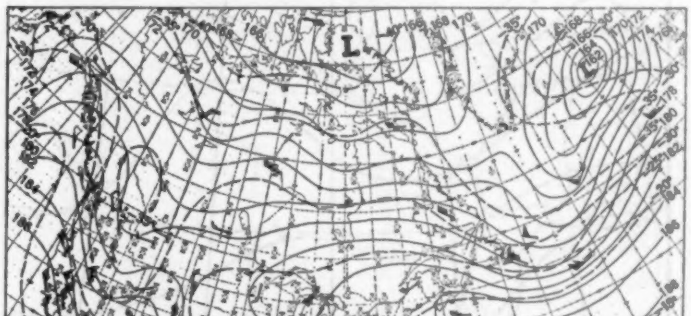

FIGURE 4.—500-mb. chart for 1500 GMT, December 22, 1952. Compare contour directions at corresponding points on the constant vorticity trajectory shown on figure 2.

A condition for the use of the formula is that the wave be symmetrical, but this wave was asymmetrical by the time of deceleration of the surface Low. The formula is based on the conservation of vorticity. This principle of course may be applied to construct constant vorticity trajectories, as described in Rossby [8], and thus to obtain trough movements. The analyzer developed by Wobus [9] was used to make such a trajectory on the 1500 GMT, December 21, 500-mb. chart (fig. 2). The result shows that the southern portion of the trough would be expected to continue moving rapidly eastward. This can be verified by checking the direction of the contour at the same location on the 1500 GMT, December 22, 500-mb. chart (fig. 4). No constant vorticity trajectory seemed to indicate a slow movement of the northern portion of the trough.

So far at 500 mb. only the wind field as represented by contours has been considered but the temperature field should be considered as well. The temperature analysis suggested the use of the 1000–500 mb. thickness (mean isotherms) which is the primary synoptic tool of Sutcliffe [10]. From a comparison of his selected patterns with the pattern of the thickness lines for 1500 GMT, December 21 (fig. 5), it appeared that the thermal trough of this storm was an example of "the cyclonic thermal involution." Of this type Sutcliffe states that the reversed thermal over the cyclonic region is not in harmony with wave-like thermal steering and the situation is liable to evolve further with little movement. Moreover it appeared that the attendant thermal ridge east of the trough was an example of "the difluent thermal ridge," of which he states that with weak thermals ahead there is little tendency for pressure systems to break and run through the pattern. From these considerations the storm might have been expected to move slowly.

Next, George's objective method [11] for obtaining a quantitative forecast of the speed of surface Lows was tried. The method combines wind and thermal effects and characteristics of the upper level trough. Computations made from graphs in his Report No. 2 by using data from 1500 GMT upper level charts and 1830 GMT surface charts of December 21 gave a forecast speed of 22 knots for the next 24 hours. This forecast speed happens to be

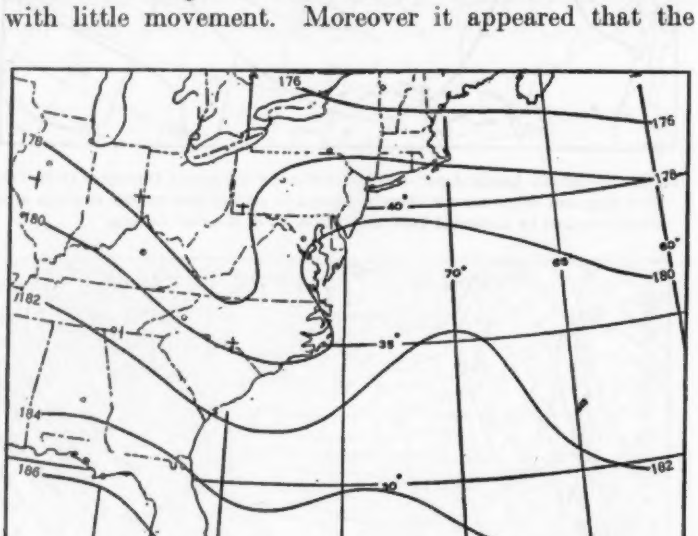

FIGURE 5.—1000–500 mb. thickness chart for 1500 GMT, December 21, 1952. Thickness, labeled in hundreds of feet, is proportional to mean virtual temperature. The thermal trough is an example of "the cyclonic thermal involution" and the thermal ridge east of the trough is an example of "the difluent thermal ridge" described by Sutcliffe [10].

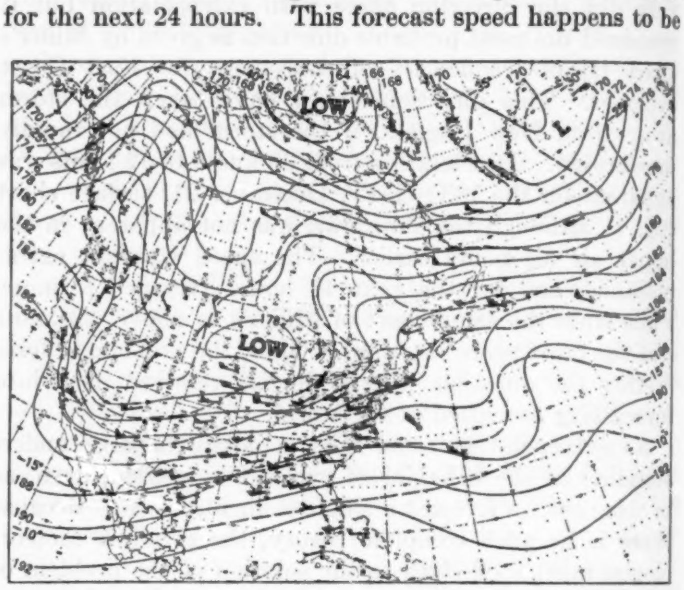

FIGURE 6.—500-mb. chart for 1500 GMT, December 23, 1952. Note intensification of ridge to east of trough and change in westerlies to single band over Labrador and the western Atlantic. Compare with figures 2 and 4.

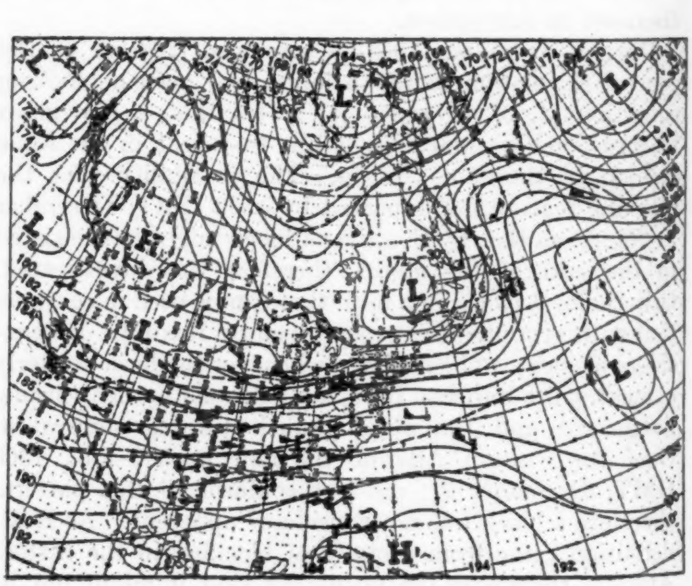

FIGURE 7.—500-mb. chart for 1500 GMT, December 25, 1952. Ridge now resembles fourth or blocking stage in the "index cycle" described by Namias and Clapp [12].

the same as the past speed of the 500-mb. trough. The speed of the surface Low observed for the six hours before 1830 GMT, December 21, was already only 12 knots. In Report No. 3 George says that for upper level troughs described as "slow" or "stationary steepening" the speed of the Low at the surface would be one half the value given in Report No. 2. Only from the comparison with Sutcliffe's selected patterns, however, might the trough have been described as "slow" for it had not yet shown any deceleration. The use of the correction indicated in Report No. 3 gave a forecast speed of 11 knots, obviously much closer to the observed speed of 8 knots for the next 24 hours.

After the storm's deceleration, characteristics appeared in the circulation which indicated that blocking conditions in the western Atlantic might be forming. On December 23 (fig. 6) the 500-mb. ridge to the east of the East Coast trough had been reinforced by a faster moving ridge from Canada (compare figs. 2, 4, and 6). The westerlies over North America, which had been split into two wave trains in different latitude bands (figs. 2 and 4), now appeared in one band over Labrador and the western Atlantic. Namias and Clapp [12] observed that when the westerlies change in this manner they often go through a complete "index cycle". Figure 6 conforms to stage two of the "index cycle" they describe. Figure 7, 1500 GMT, December 25, resembles the fourth stage characterized as blocking.

The easternmost point along the east-northeast track was reached by the storm at 1830 GMT, December 23 (fig. 8). Thereafter, the storm track changed abruptly to the north and the storm accelerated (see fig. 9). The 500-mb. chart nearest to the time of recurvature, 1500 GMT, December 23 (fig. 6) shows that the trough associated with the storm had joined with a Low from the west. The trough rotated northward around the 500-mb. Low and the surface storm also moved northward. [On the surface chart at the time of recurvature (fig. 8) this Fujiwhara effect [13] is not obvious, in fact it might have been expected that the storm in the East, being deeper than the Low in the Midwest, would steer the Midwest Low southward.] Soon after the old trough and the new Low combined, the Low deepened greatly as seen on the 1500 GMT, December 25, 500-mb. chart (fig. 7). With the deepening, the strength of southerly flow over the surface Low off the East Coast increased and the storm accelerated. Soon after the recurvature and acceleration the precipitation from the storm ended over all but extreme northern New England.

The entire movement (the deceleration, slow motion, recurvature, and acceleration) was one part of the start of blocking conditions in the western Atlantic. On the 500-mb. chart for 1500 GMT, December 25 (fig. 7), Rex's criteria for a block are met, and for the period December 20–24, the 700-mb. height departure from normal chart (fig. 10) showed that heights were above normal off the East Coast, in agreement with Elliott and Smith's criteria. The block persisted the rest of the month and influenced the behavior of succeeding storms.[1]

[1] See preceding article by Hawkins.

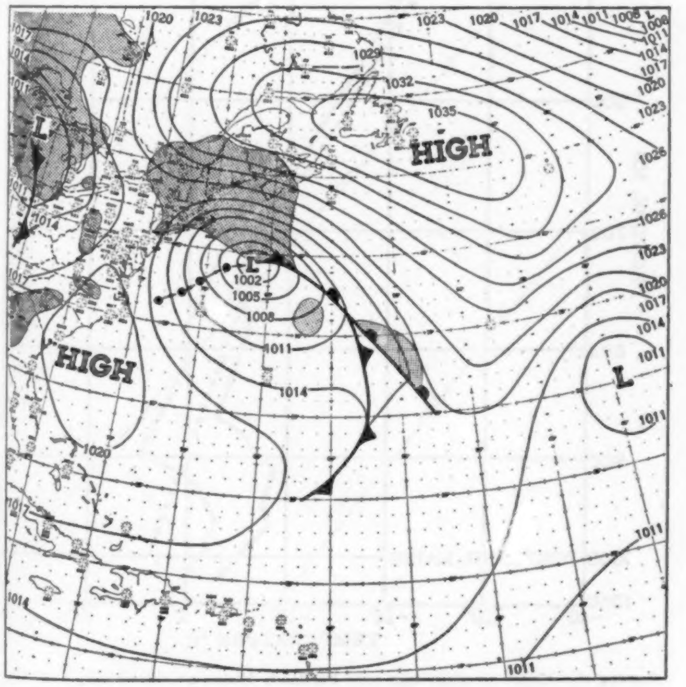

Figure 8.—Surface weather chart for 1830 GMT, December 23, 1952. Small circles connected by arrows indicate past positions of the main Low at 12-hour intervals. This was the farthest-east position reached by the storm.

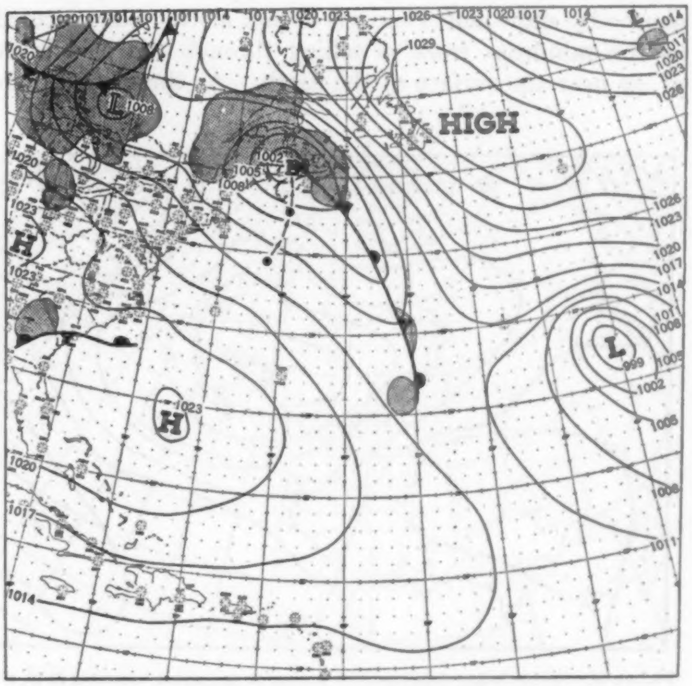

Figure 9.—Surface weather chart for 1830 GMT, December 24, 1952. Small circles connected by arrows indicate past positions of main Low at 12-hour intervals. Storm is now moving northward at an accelerated speed.

ASSOCIATED WEATHER CONDITIONS

A variety of weather conditions were associated with this Atlantic coastal storm but sleet was the most striking. The precipitation began predominantly as rain in the Carolinas and moved northward into New York State and New England where it remained for approximately 48 hours. For 18 consecutive hours sleet mixed with snow, rain, and freezing rain fell at Augusta, Maine. Boston, Mass., reported sleet for 15 consecutive hours. Similar conditions were prevalent throughout New England. Airway hourly sequences indicated that fog, drizzle, freezing drizzle, and occasional snow pellets and snow grains also appeared mixed with the sleet. The precipitation was accompanied by strong winds along the coast.

A surface layer of cold air covered New England as the storm moved northward. Surface temperatures were relatively cold with Nitchequon, Quebec, on the north side of the High, reporting −1° F. while Caribou, Maine was the coldest reporting spot in the United States with a maximum of 19° F. and 16° F. respectively for December 21 and 22. The surface temperatures in the area hovered around freezing except right along the coast at such places as Nantucket, Mass. Temperature conditions aloft are illustrated by figure 11 which shows the upper air soundings for Portland, Maine for 1500 GMT, December 22, 23, 24. The first sounding was taken about 7 hours prior to the snow, the second sounding was taken about 12 hours after the sleet began, and the third sounding about 3 hours following the end of the precipitation at that station. The changes of the upper air temperatures show why snow aloft changed to rain aloft. Sleet formed as the raindrops froze in falling through the cold layer of air near the surface of the earth. As these conditions existed over a relatively large area, sleet was widespread, extending from Allentown, Pa., to Syracuse, N. Y., eastward over New England and northward to Caribou, Maine.

In spite of the prolonged and widespread precipitation, damage was not extensive because the amounts were not excessive. Much inconvenience was caused by the accumulation of more than 1 inch of sleet on the ground during 10 to 18 hours. Portland, Maine reported a severe ice storm on the 23d that put many power and telephone lines out of action for several days. Nantucket, Mass., although reporting no sleet, did report 2.48 in. of precipitation for the period December 22–23, the greatest 24-hour amount for the month. A total of 4 inches of snow fell in parts of southern New England and mountainous areas but changed rapidly to rain and sleet.

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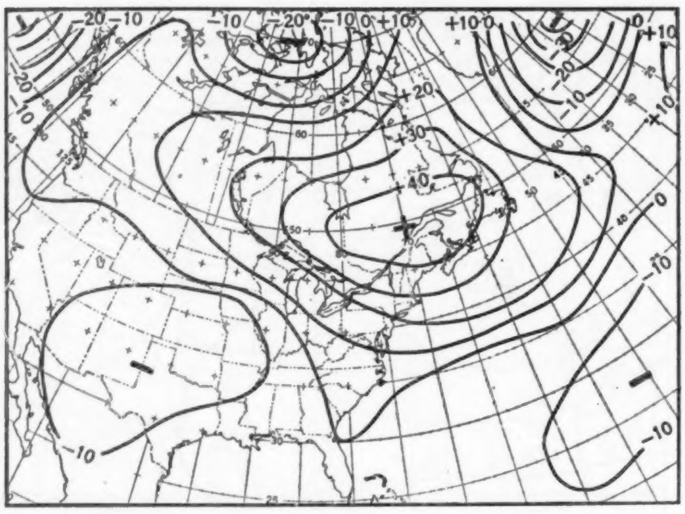

FIGURE 10.—700-mb. height departure from normal for the period December 20–24, 1952 covering the time of the storm in New England. Note the above normal heights over eastern Canada and the western Atlantic and compare with figure 3. Chart prepared by Extended Forecast Section, U. S. Weather Bureau.

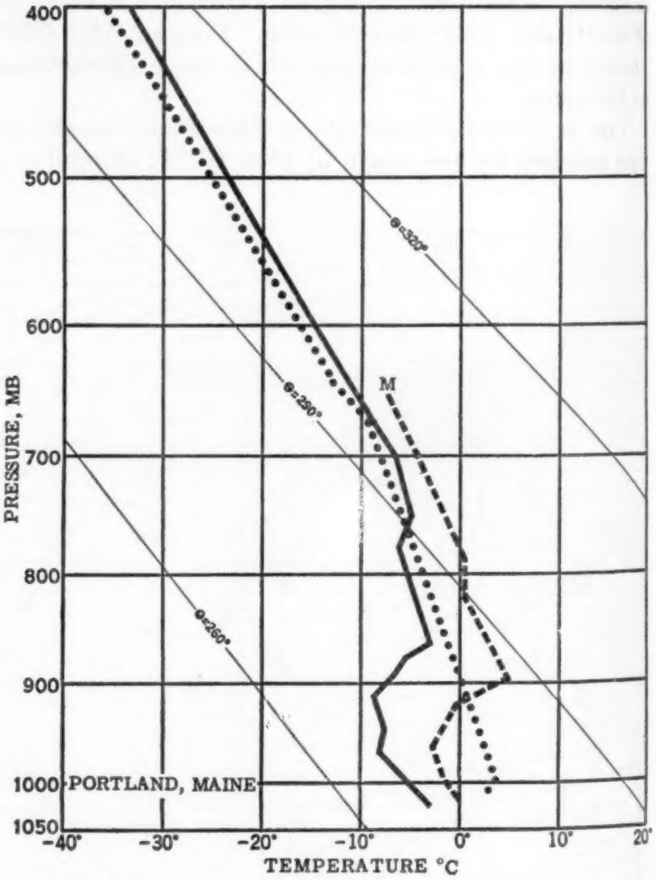

FIGURE 11.—Upper air soundings over Portland, Maine at 1500 GMT, December 22 (solid line), December 23 (dashed line), and December 24 (dotted line). The temperature changes show why snow aloft soon changed to rain aloft then froze as sleet while passing through the layer of cold air near the surface.

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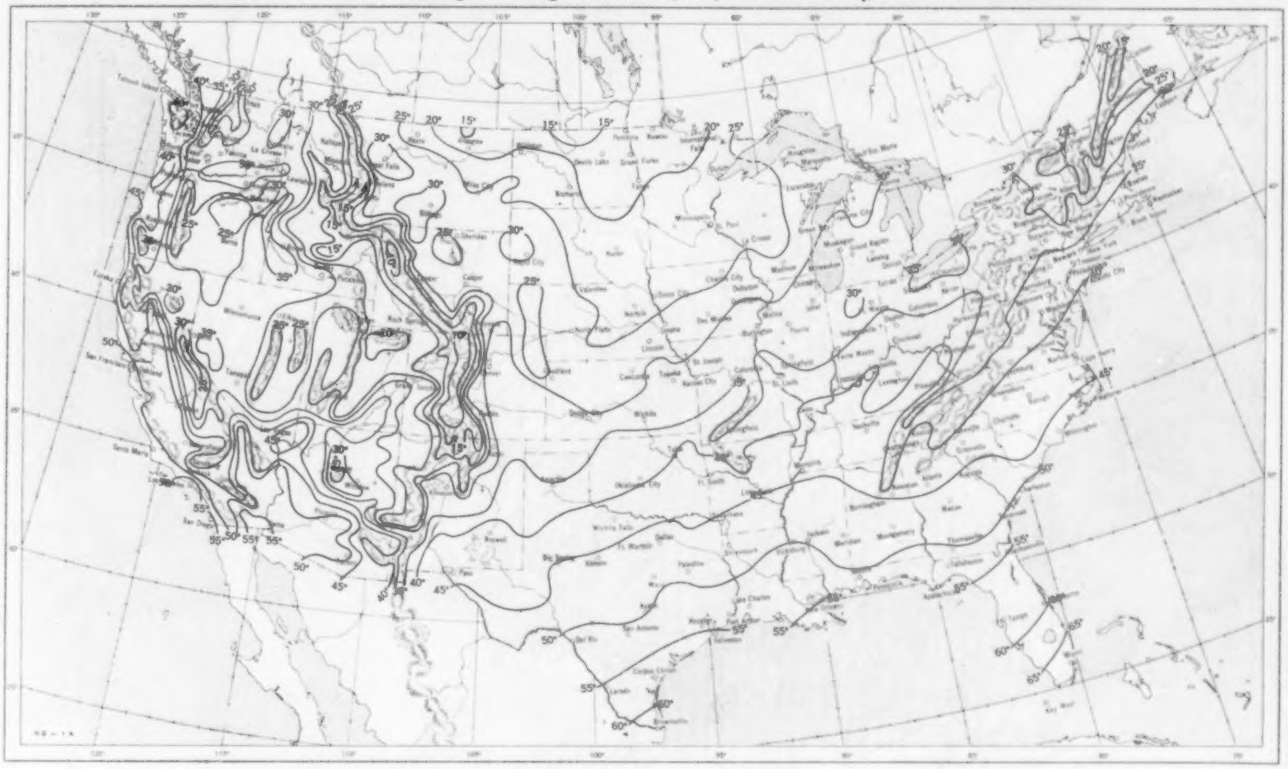
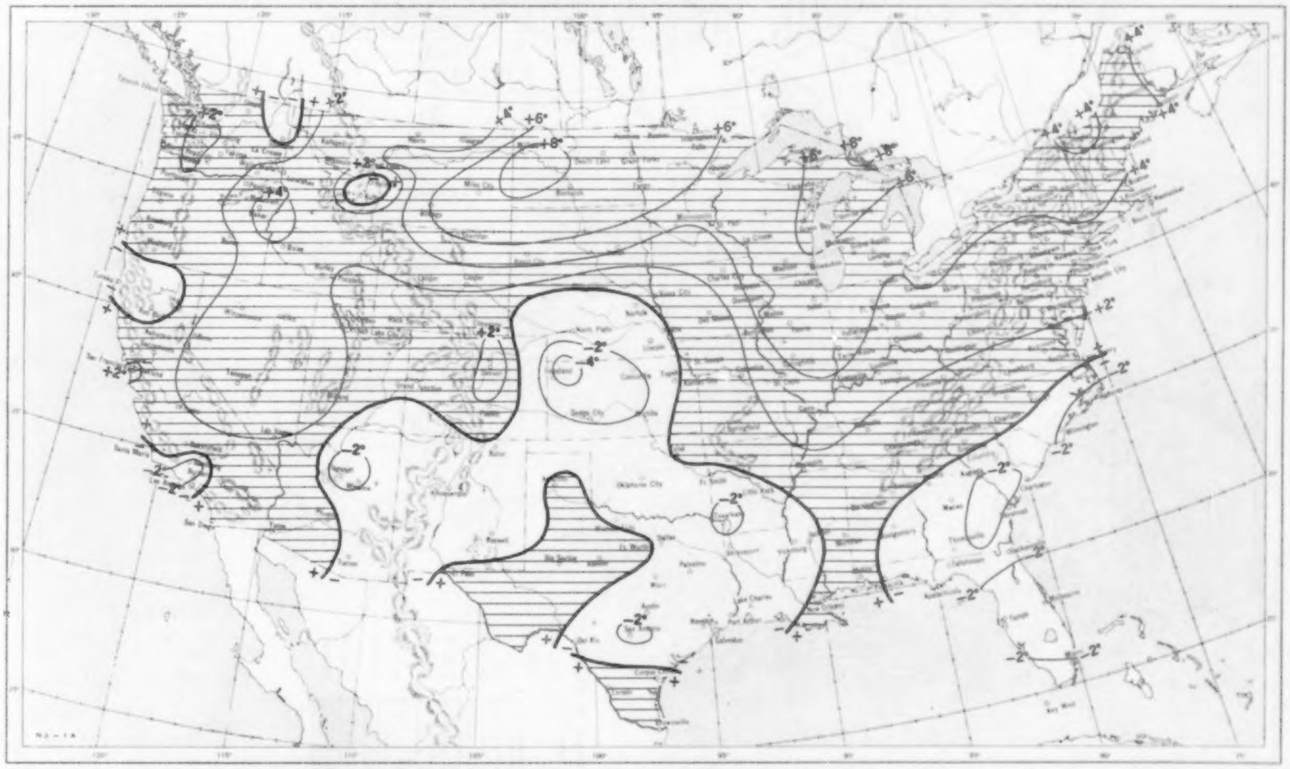
U. S. GOVERNMENT PRINTING OFFICE: 1953

Chart I. A. Average Temperature (°F.) at Surface, December 1952.

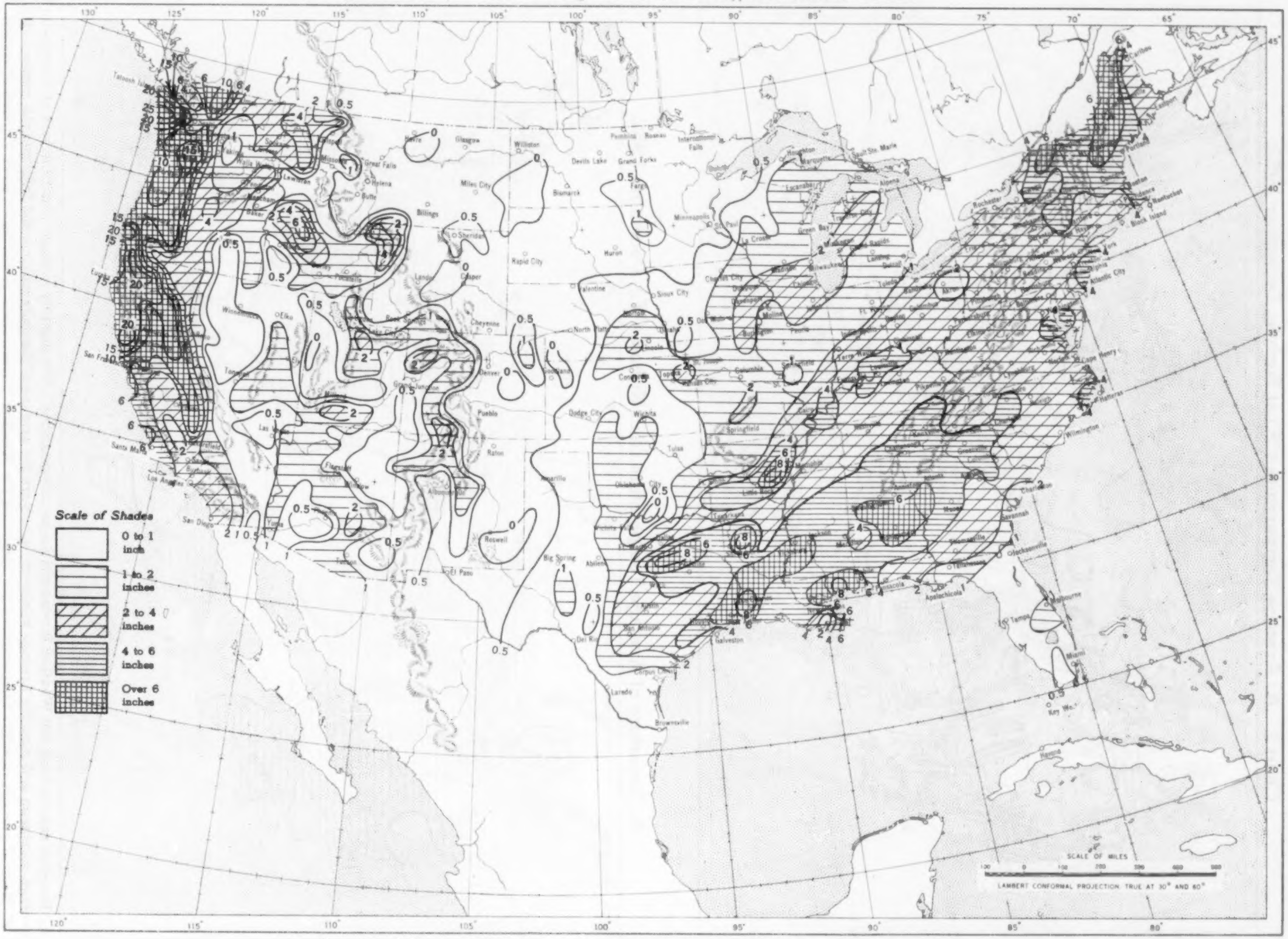


B. Departure of Average Temperature from Normal (°F.), December 1952.



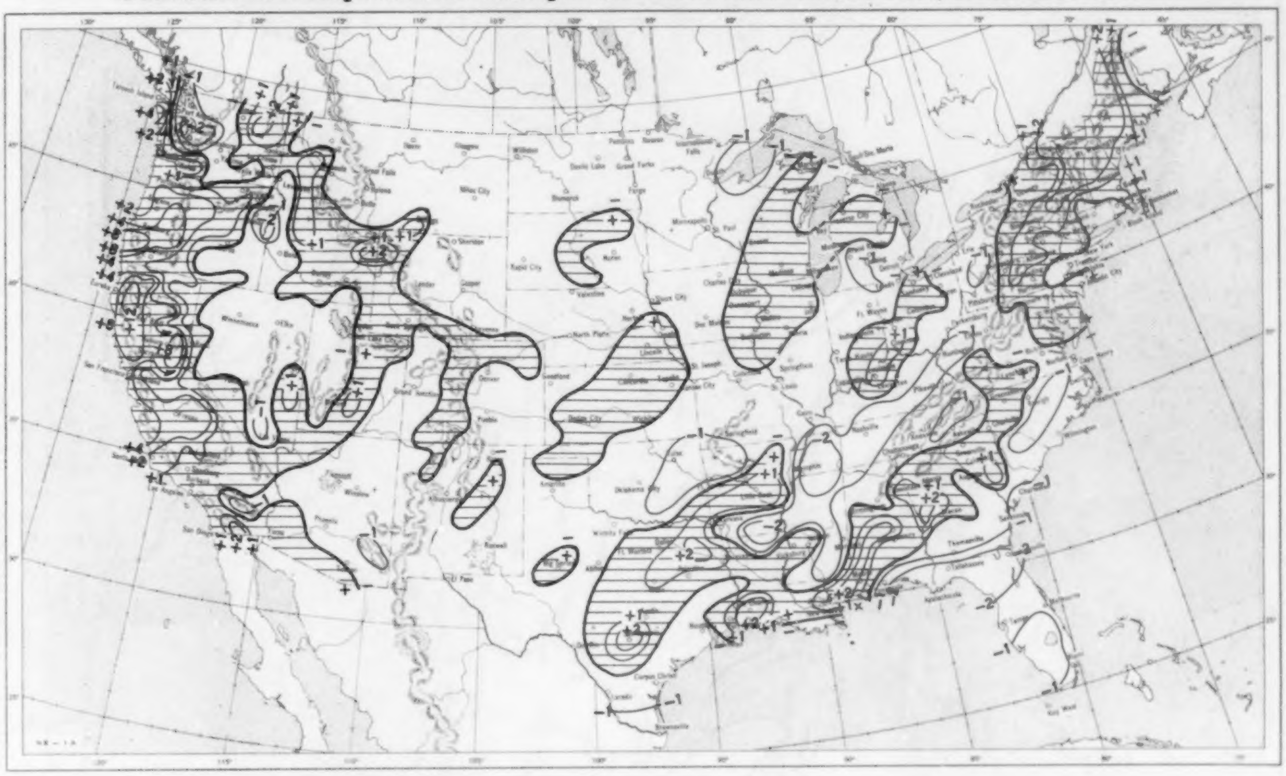
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), December 1952.

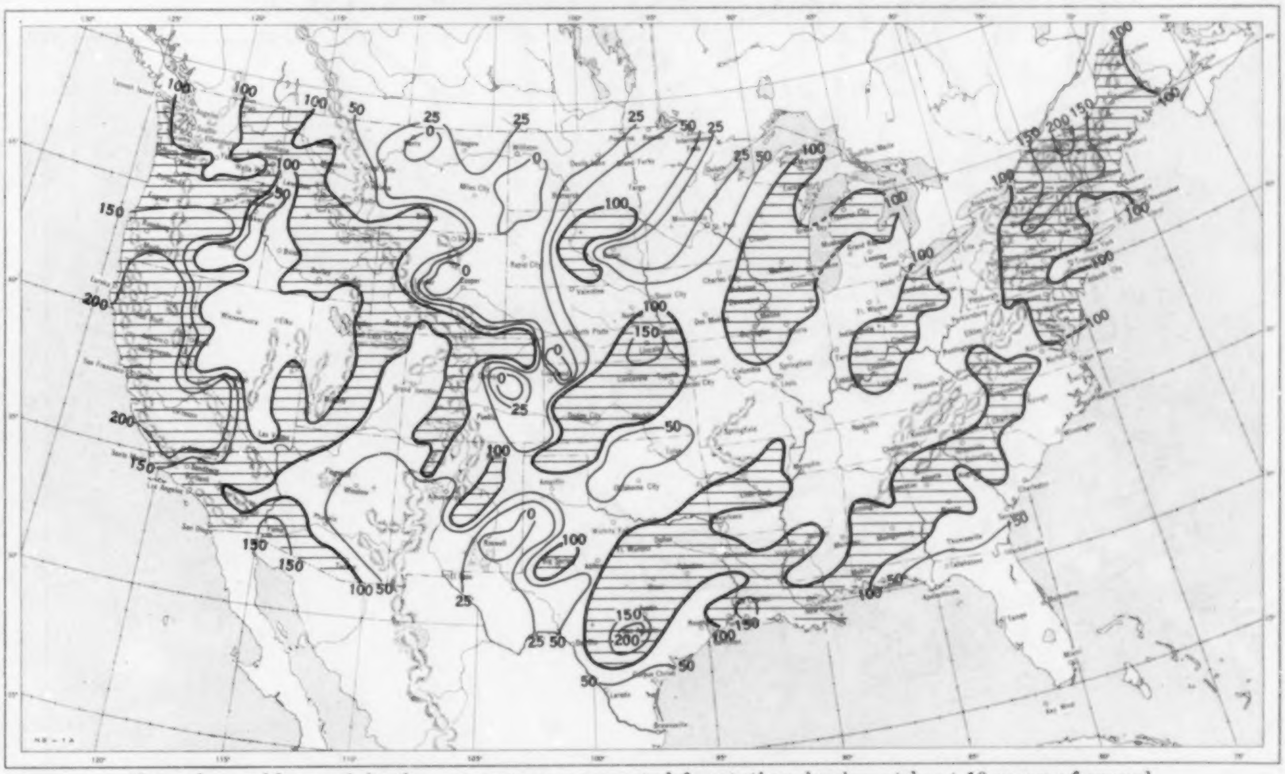


Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), December 1952.

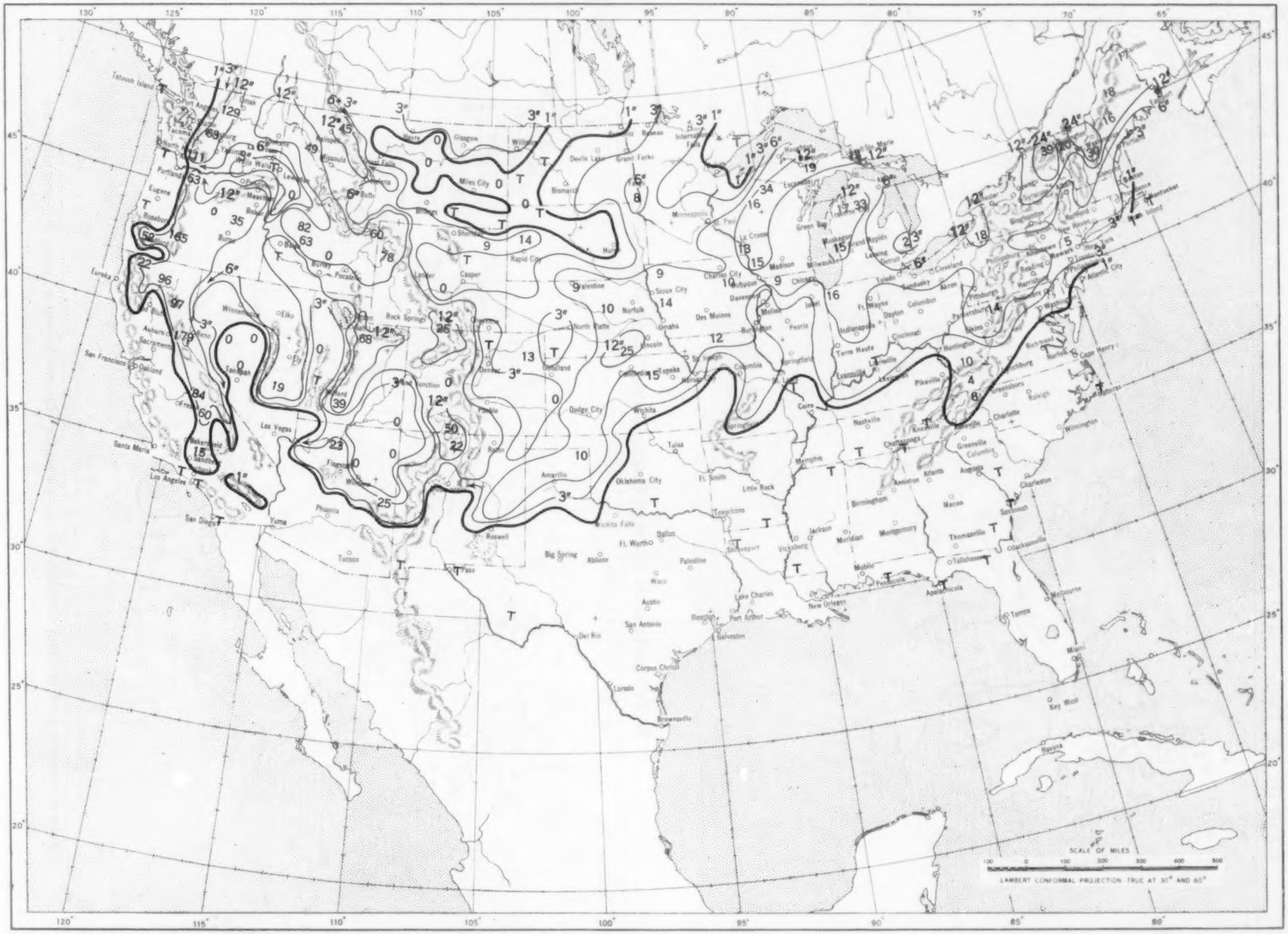


B. Percentage of Normal Precipitation, December 1952.



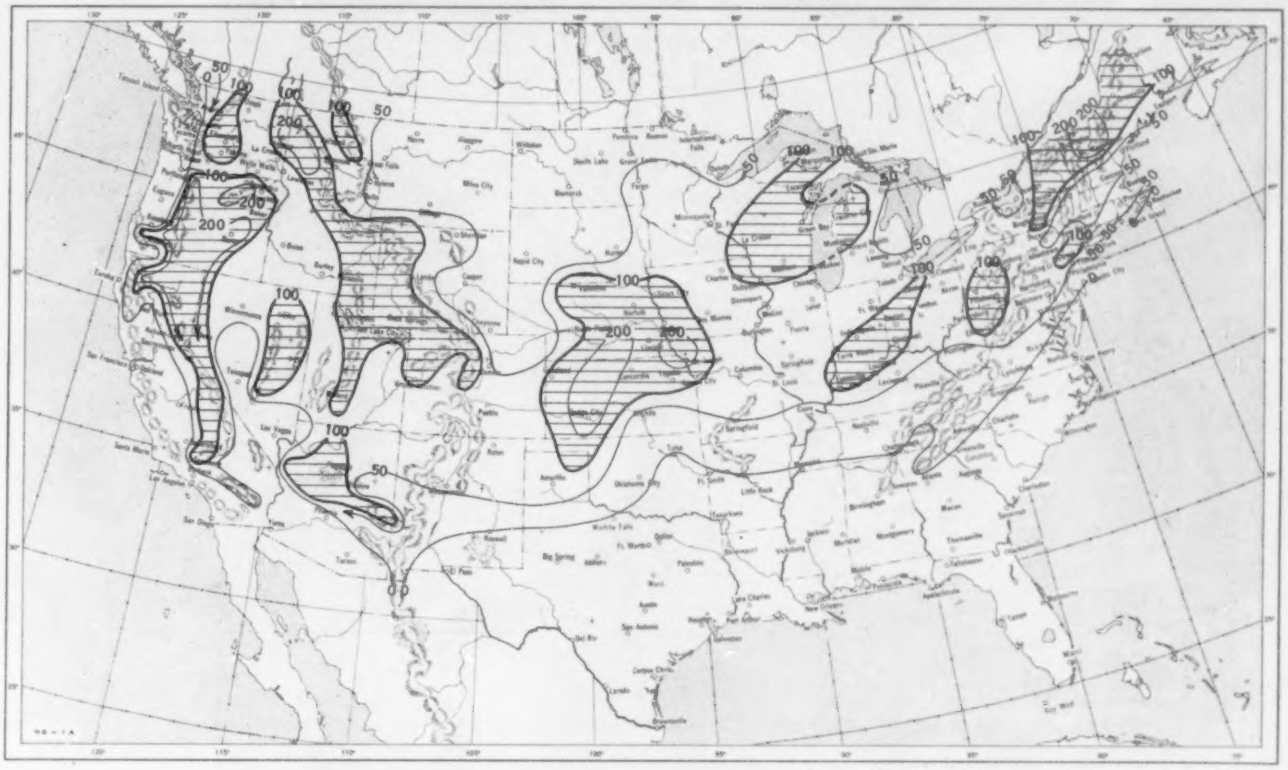
Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart IV. Total Snowfall (Inches), December 1952.

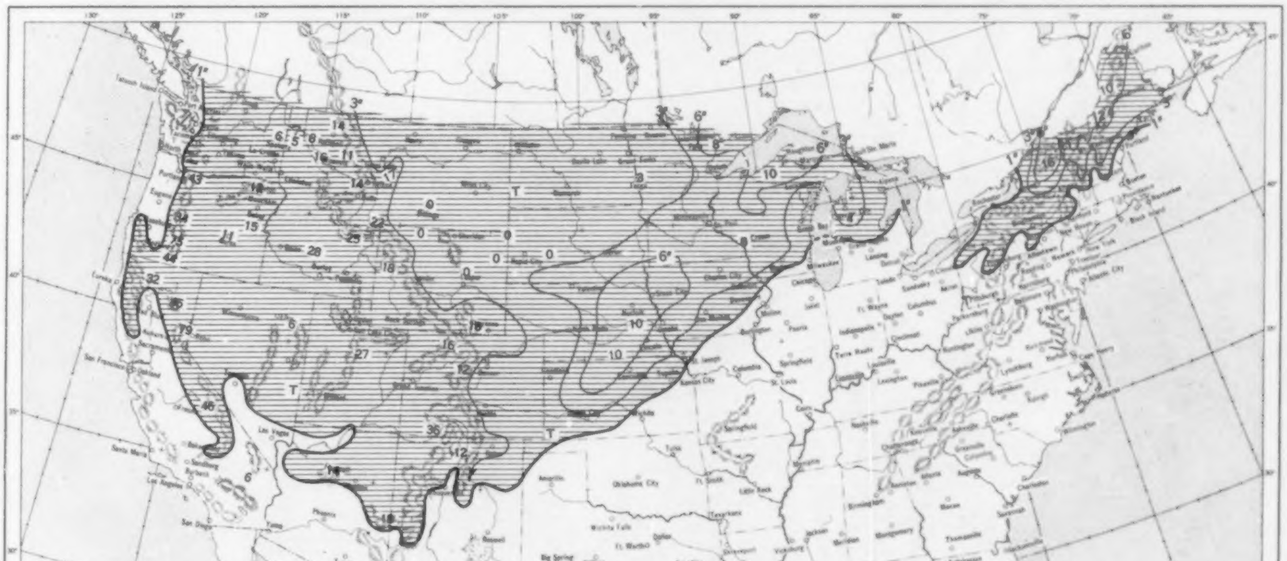


This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

Chart V. A. Percentage of Normal Snowfall, December 1952.

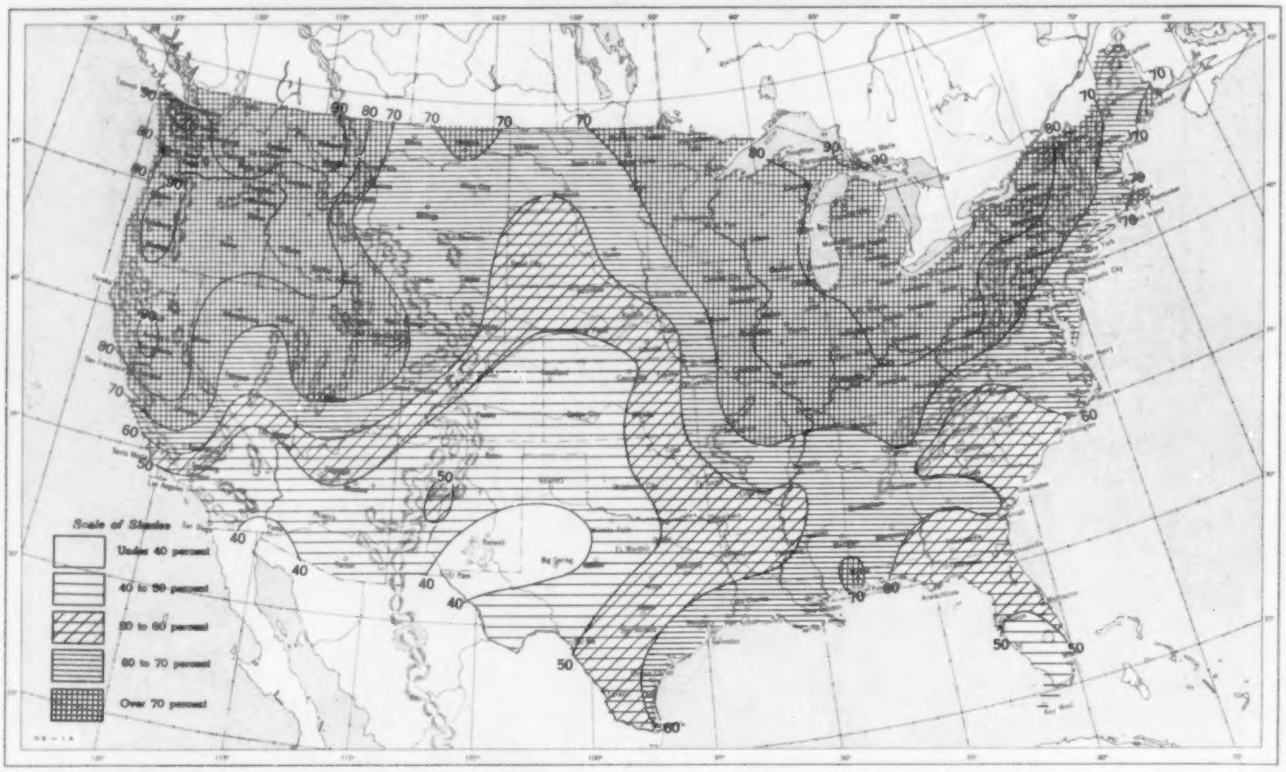


B. Depth of Snow on Ground (Inches), 7:30 a. m. E. S. T., December 30, 1952.

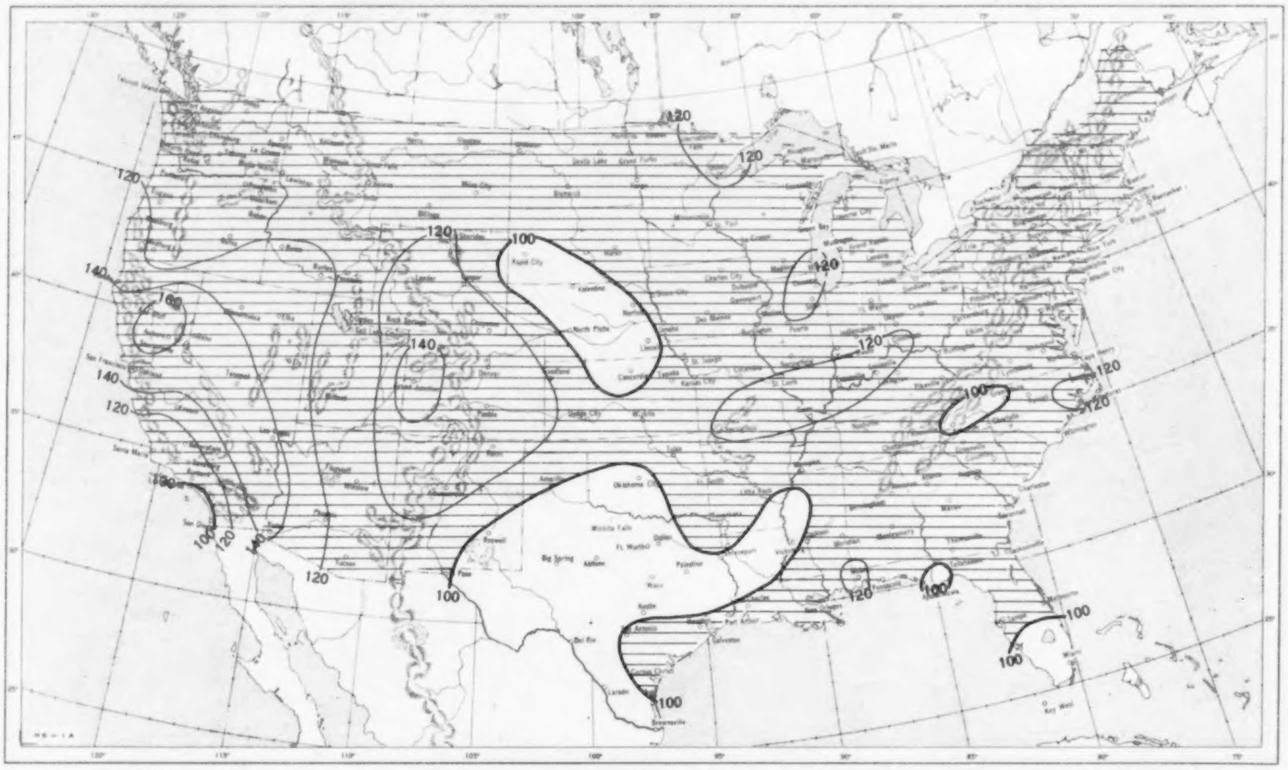


A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record.
B. Shows depth currently on ground at 7:30 a. m. E. S. T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows greatest southern extent of snowcover during month.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, December 1952.

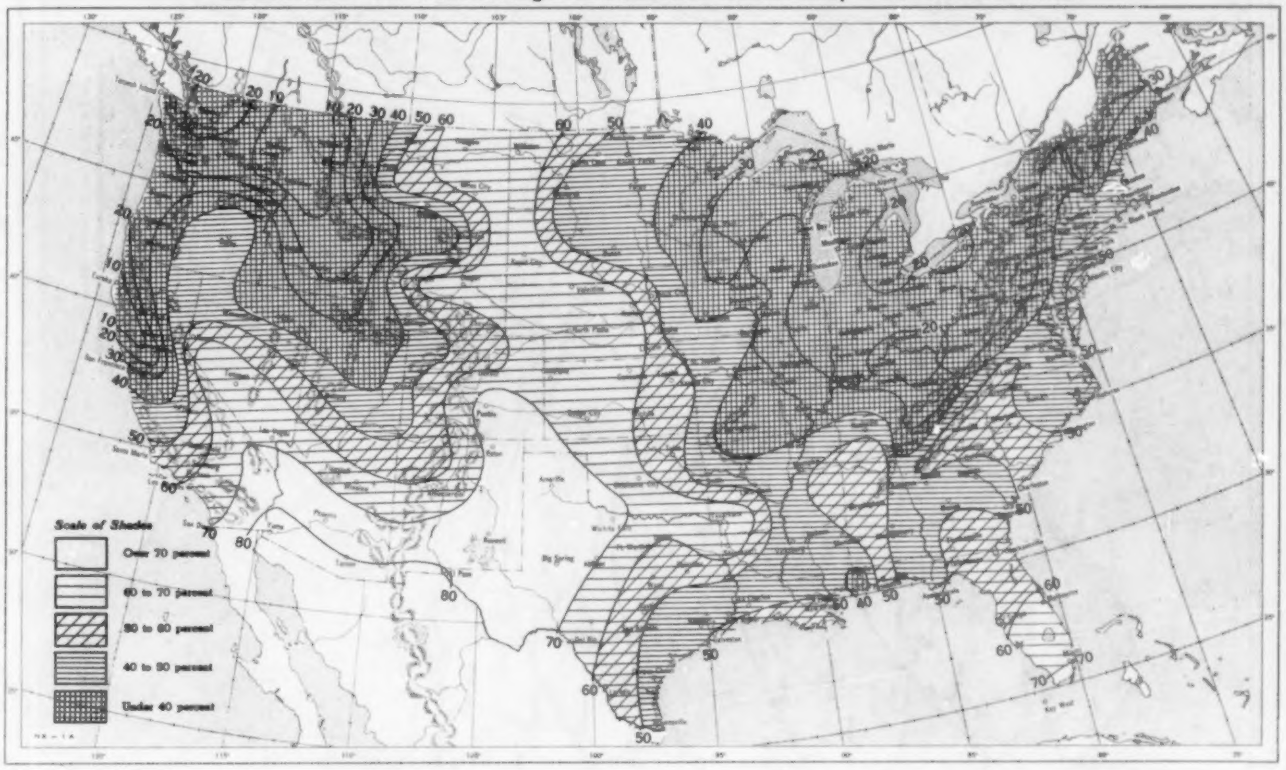


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, December 1952.

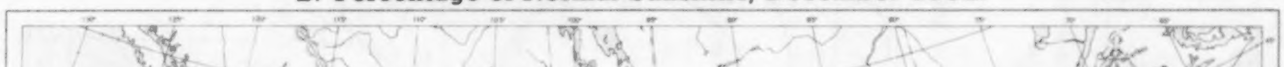


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, December 1952.



B. Percentage of Normal Sunshine, December 1952.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, December 1952. Inset: Percentage of Normal Average Daily Solar Radiation, December 1952.

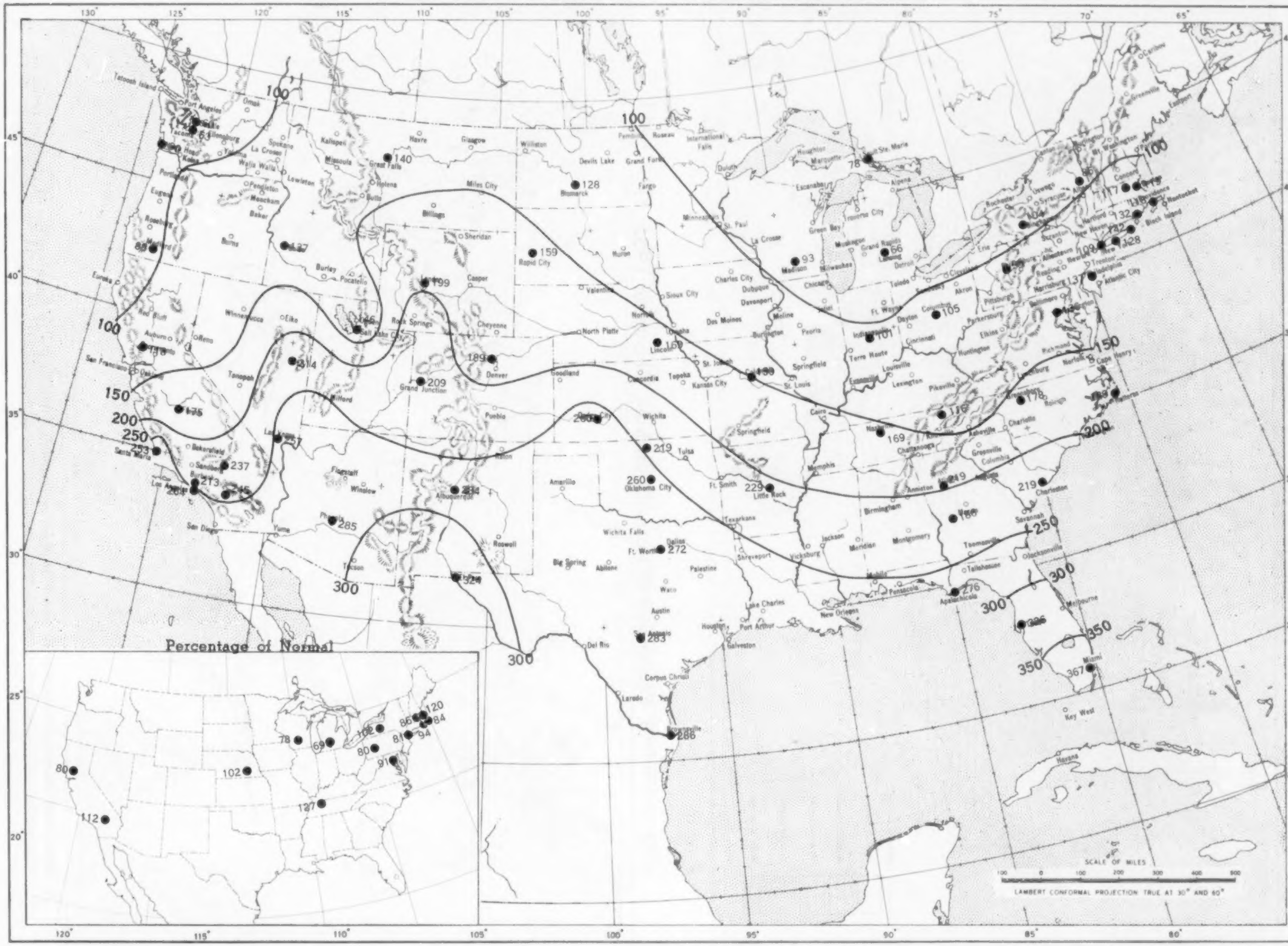
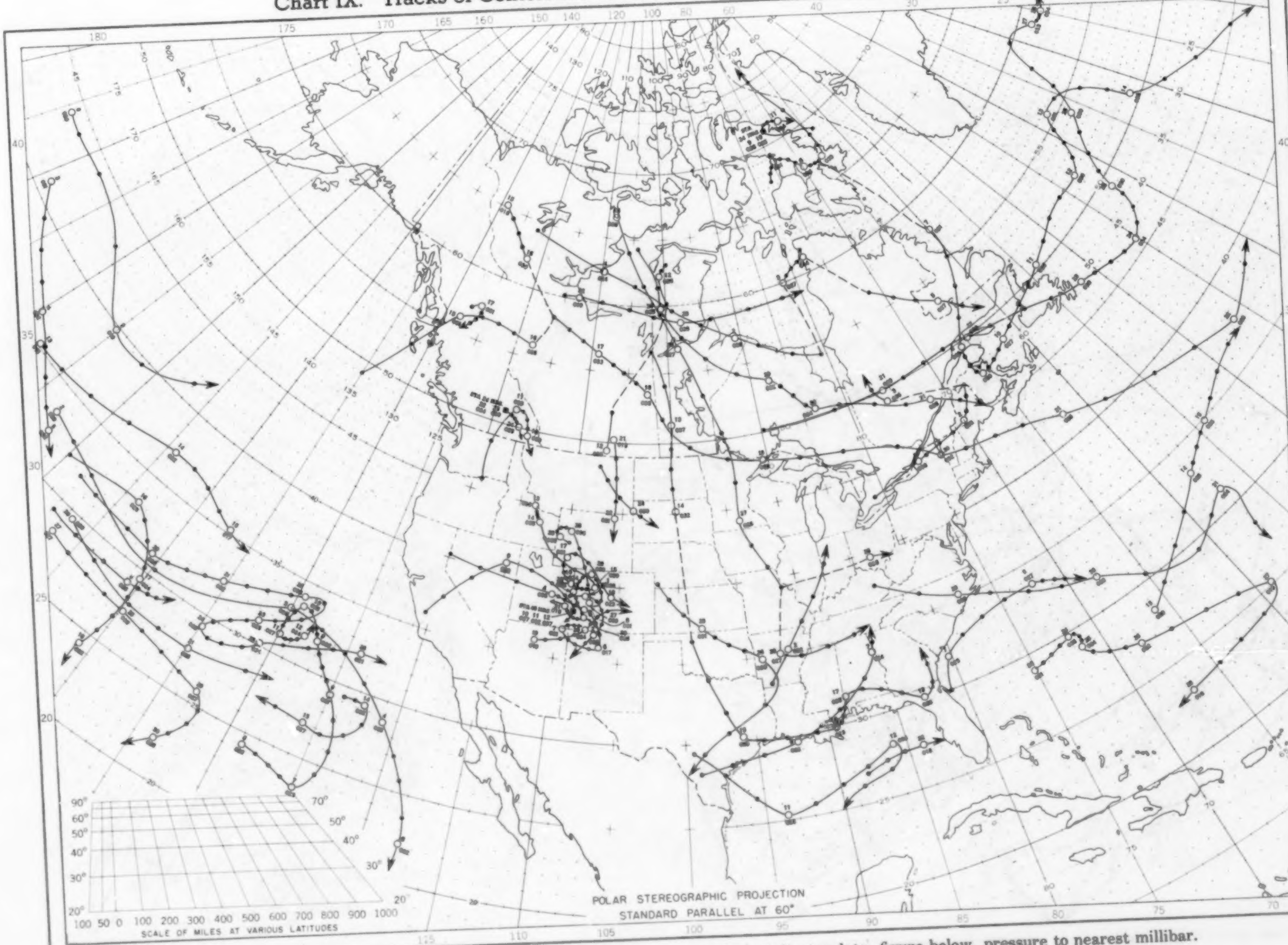


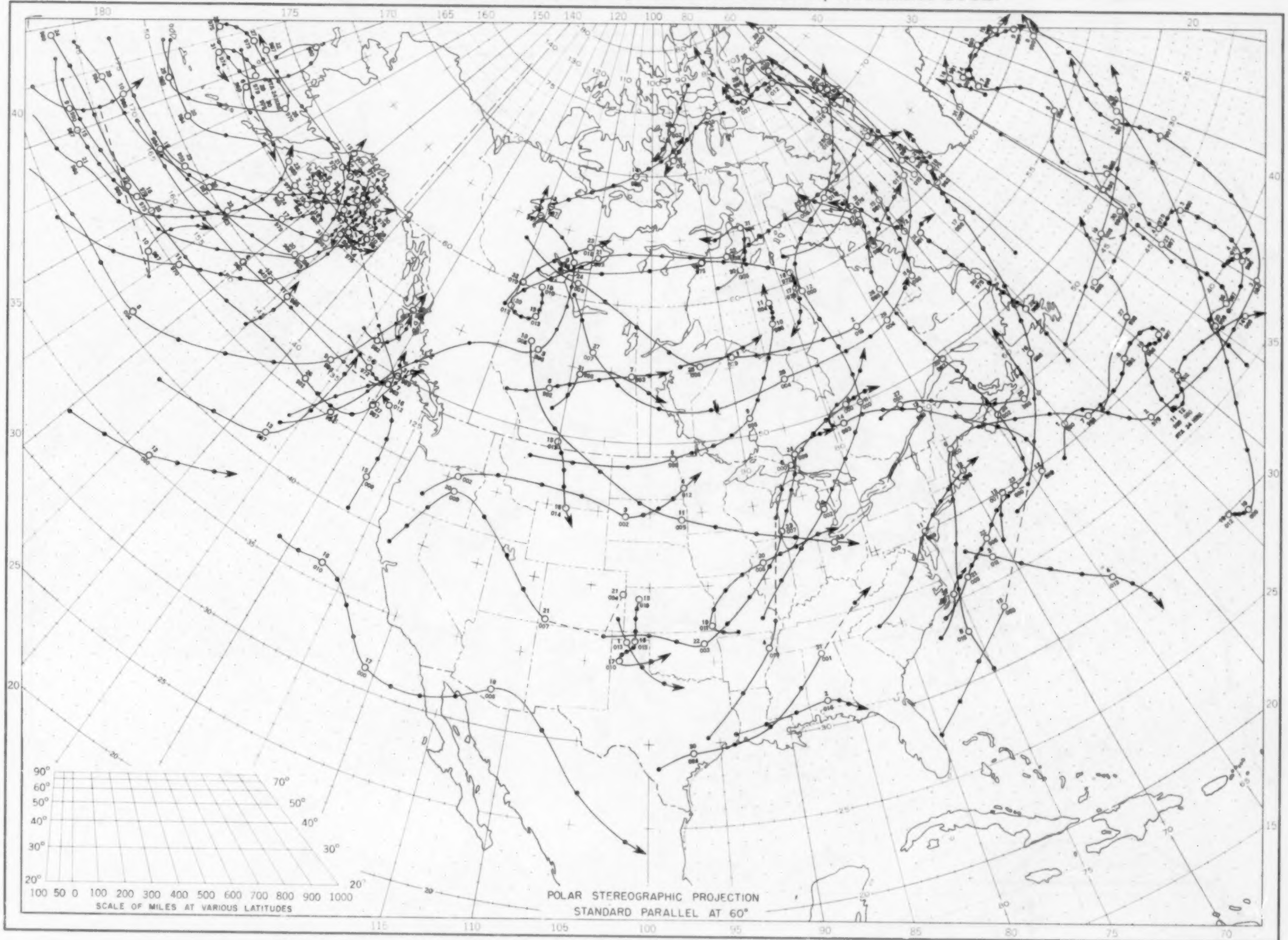
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, December 1952.



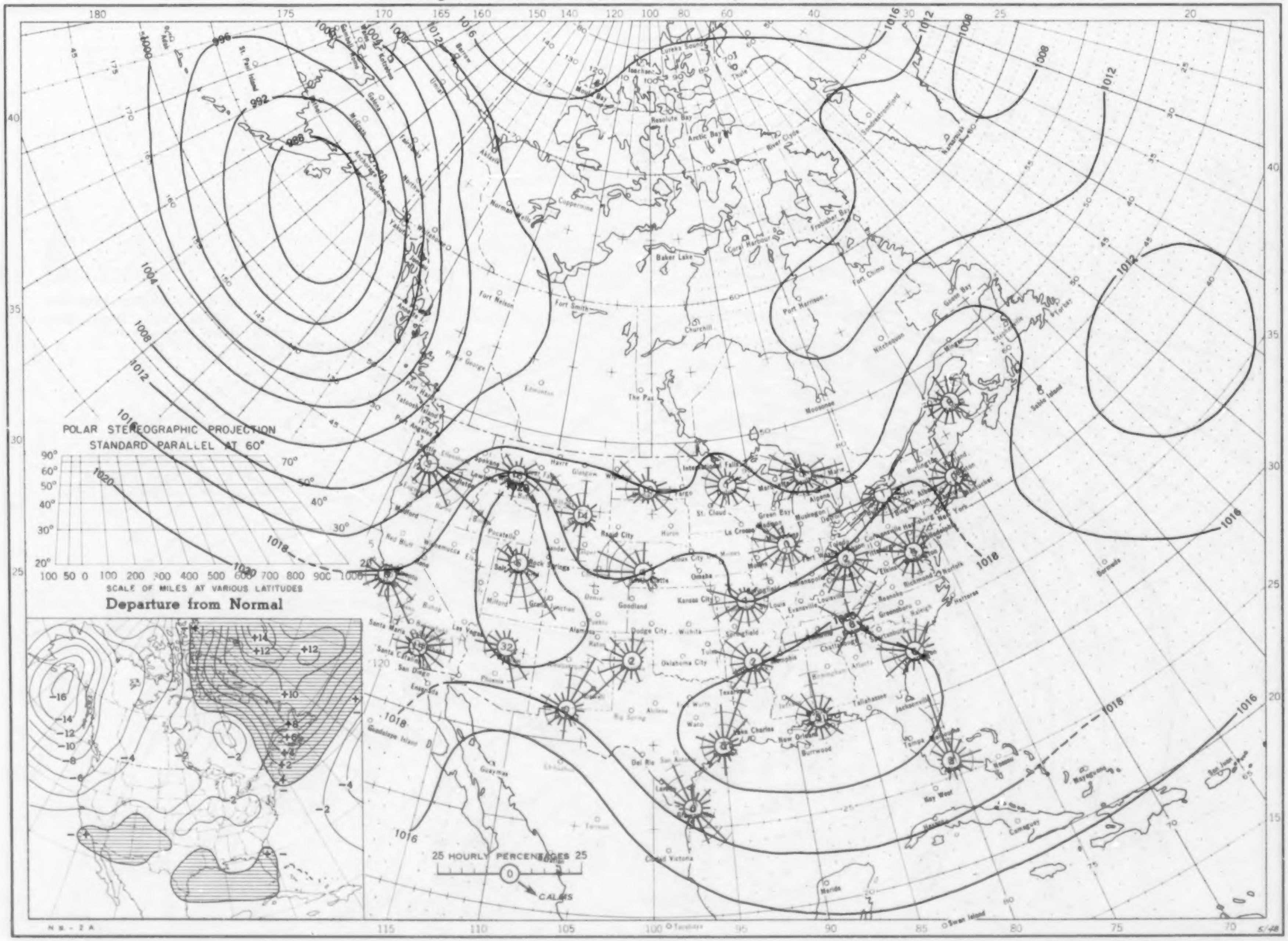
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, December 1952.



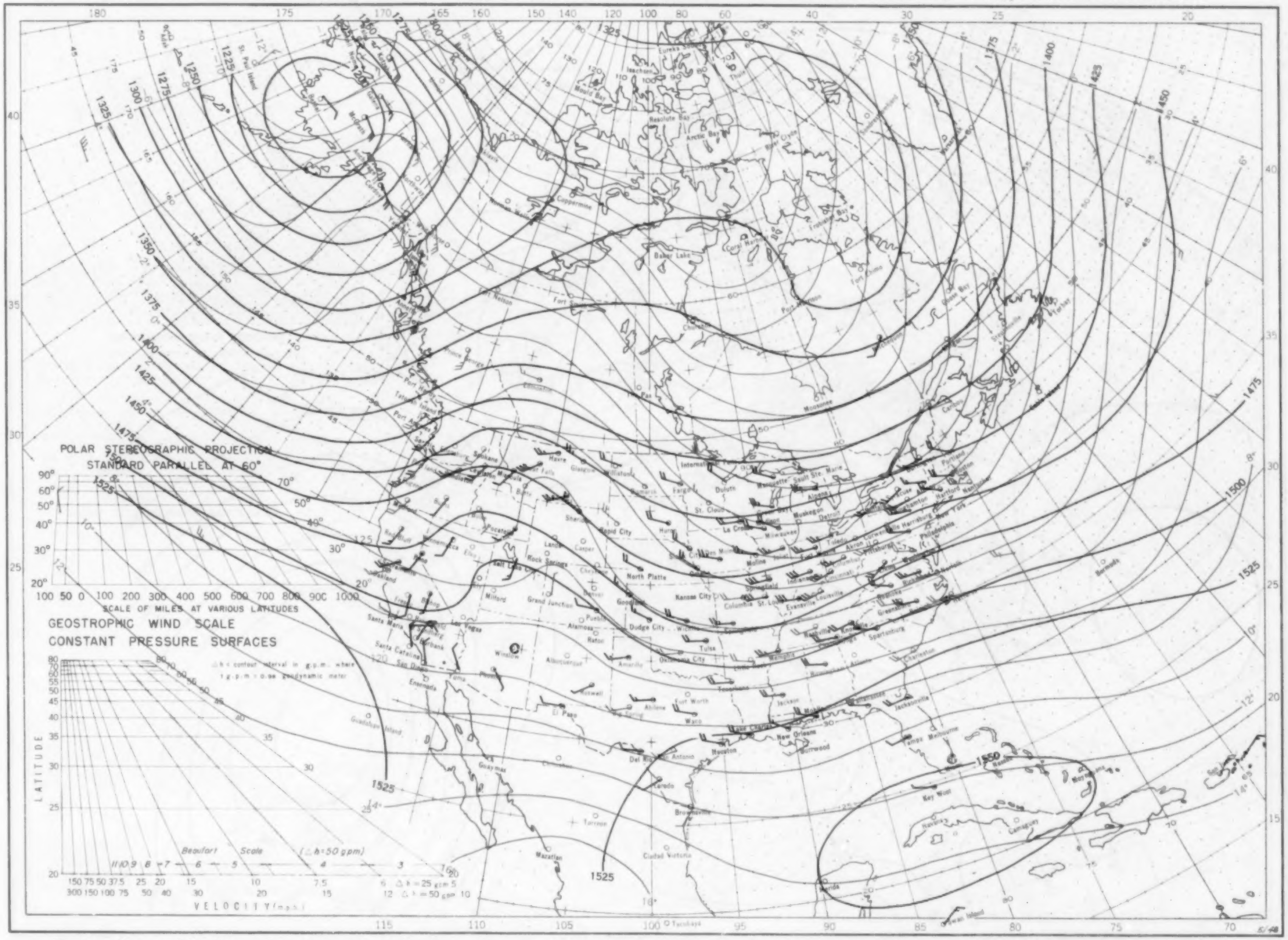
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, December 1952. Inset: Departure of Average Pressure (mb.) from Normal, December 1952.



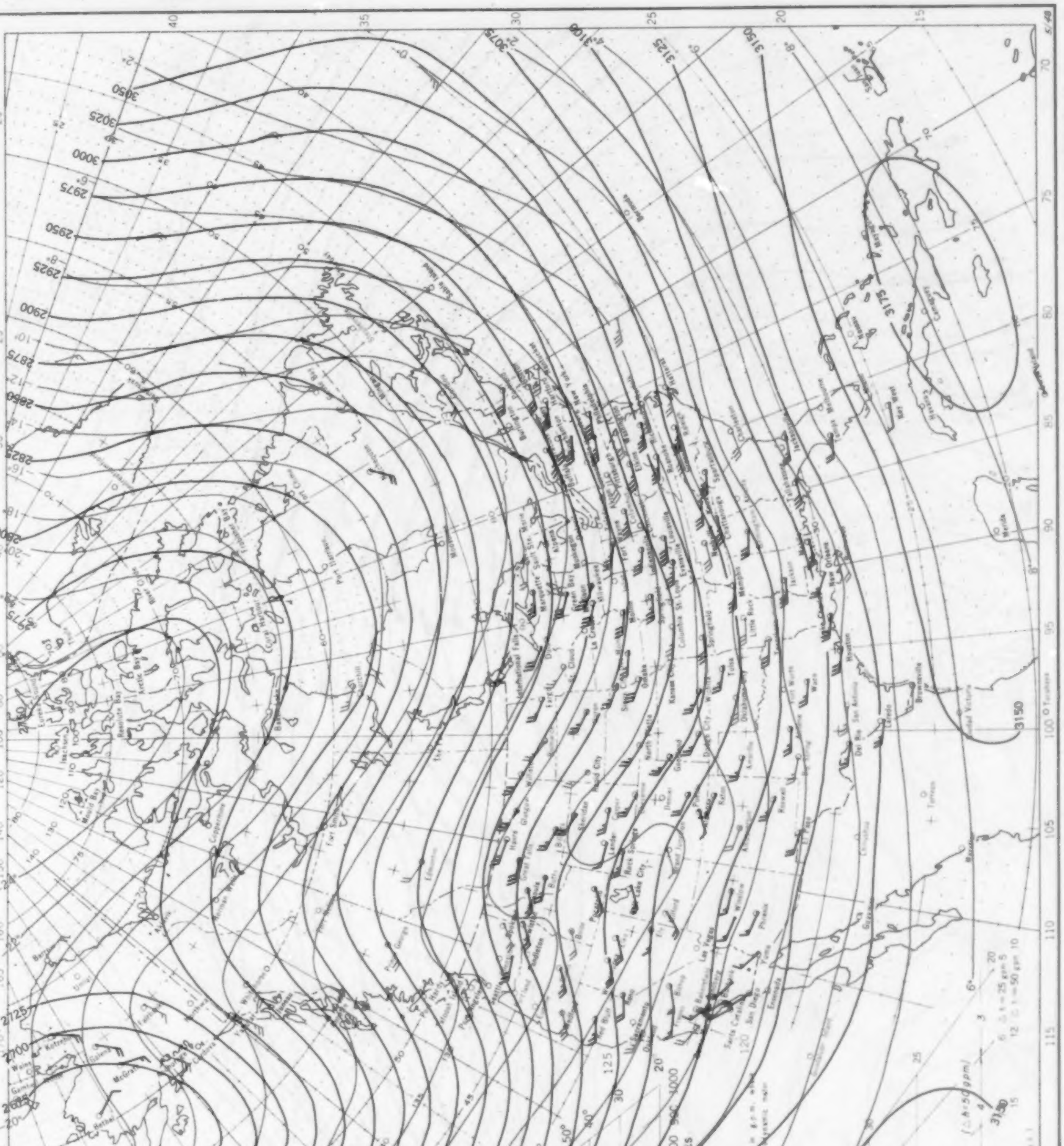
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), December 1952.



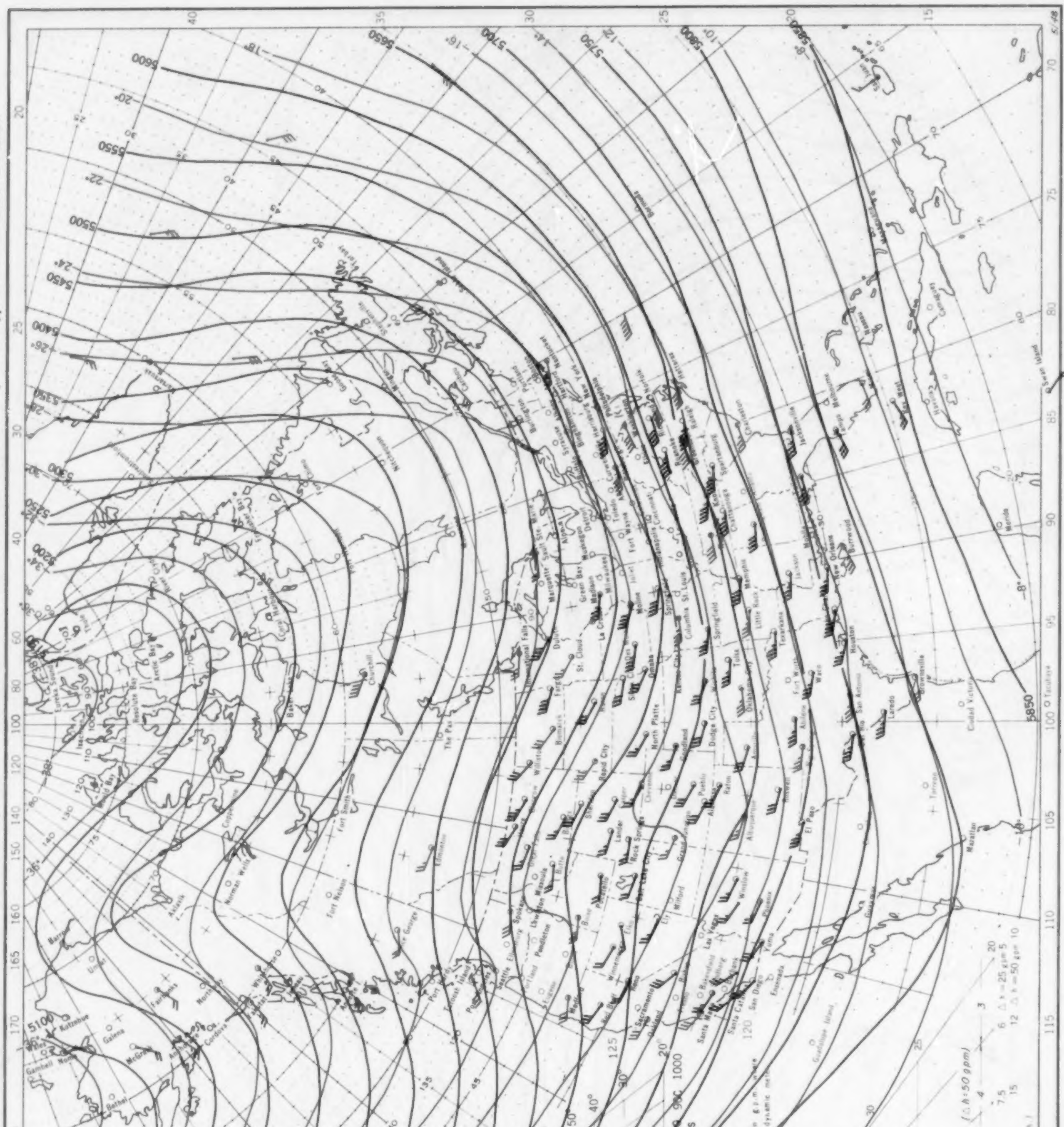
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), December 1952.



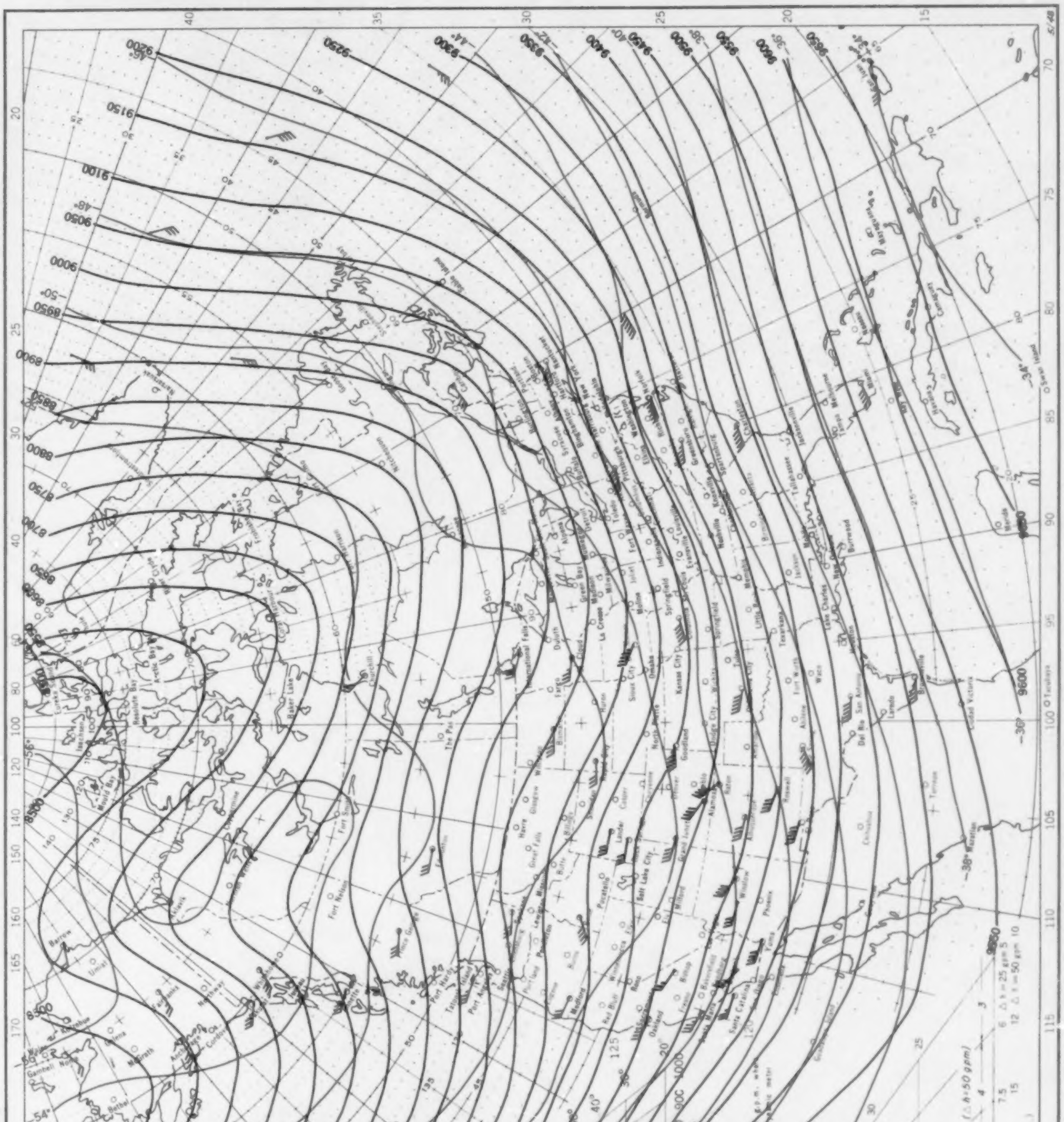
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), December 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), December 1952.



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The MONTHLY WEATHER REVIEW publishes contributions in the field of meteorology, principally in the branches of synoptic and applied meteorology. In addition, as its name implies, it carries a review of the month's weather which includes a discussion of general circulation patterns and also an analysis of some particular meteorological situation which produced striking weather conditions during the month in the United States. The issue for each month is published as promptly as these monthly data can be assembled and prepared.

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